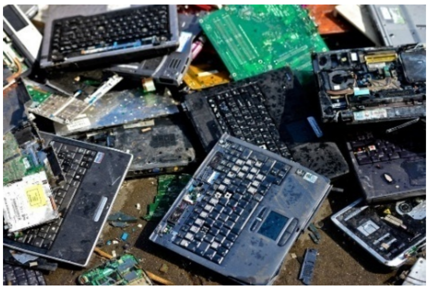
Department of Environment

Final Report

Assessment of Generation of E-Waste, Its Impacts on Environment and Resource Recovery Potential in Bangladesh



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Executive Summary

INTRODUCTION

Last few decades have witnessed a phenomenal rise in the use of electronic components and micro-chips in household appliances, office equipment, transport systems and industrial tools and devices. As these items reach end of their lifecycle, they are ending up in increasing volumes in various dump sites in almost every country of the world. Waste generated from these electronic components or electronic waste (e-waste) is currently the fastest growing global waste stream, with approximately 41.8 million tons of e-waste generated in 2014 alone. This amount is expected to be 49.8 million tons in 2018 with an annual growth rate of 4-5 percent.

Bangladesh, in conformity with the global trend and due to its ongoing rapid growth, is also using electronics-based appliances, equipment and tools at an increasing rate, in people's homes, offices, industrial unit, vehicles and communication systems. This has caused a corresponding increase in the rate of generation of e-waste.

The waste generated from the obsolete electronic devices (E-Waste) or Waste from Electrical and Electronic Equipment (WEEE) contain a number of toxic substances, including lead, chromium, and plastic additives. Often rich in precious metals and other reusable materials such as plastics, e-waste has been perceived as a source of additional income by more and more low-income and unemployed population in Bangladesh. Recycling of scrap and second-hand electrical equipment is a profitable business in developing countries like Bangladesh where there is no or little environmental regulation or occupational health laws to protect the workers who are directly exposed to health risks due to the activities involved in recycling ofe-wastes. A very small amount of used electrical goods are recycled in our country by the informal sector and the rest is released into landfills, rivers, ponds, drains, lakes, channels and open spaces. Improper recycling and recovery methods may have major impacts on the environment. Crude forms of dismantling may often lead to toxic emissions, which pollute the environment and thereby also expose the workers and the public to the harmful materials.

Assessment of generation of e-wastes is an important step towards addressing the challenges of e-waste, set targets and identify best practices for management. Availability of better e-waste data helps in preventing illegal dumping and emissions, promote recycling and create jobs in the reuse and recycling sectors.Better and effective management of this sector are also crucial for achieving targets set forth by the global Sustainable Development Goals (SDG) campaign. The government has already prepared National 3R (Reduce, Reuse & Recycle) Strategy, where e-waste issues have been addressed. The Department of Environment (DoE), under the policy direction of the Government, has undertaken various programs and projects to take this further towards fulfilling Bangladesh's commitment to the international community and achieving the stated targets of the SDG campaign. This current study is a part of this initiative of the DoE.

OBJECTIVES OF THE RESEARCH

The present study has three main objectives:

i) To estimate the amount of e-wastes generated in Bangladesh and to establish its future trend,

ii) To assess E-Wastes impacts on human health and environment and

iii) To examine the potential of value metal recovery from e-wastes for Bangladesh.

RESEARCH METHODOLOGY

To achieve the stated objectives, primary and secondary data of electrical and electronics equipment and their wastes have been collected by questionnaire survey, filed visits, interviews and formal and informal meeting with the stakeholders.

To assess the generation of e-wastes, Material Flow Analysis (MFA) method has been adopted to estimate the e-waste amount from selected electrical and electronic equipment and their future trends. Primary sales/import data of eight selected EEE items (Electric Fan, TV, Air conditioner, Fridge, IT related equipment, Cell phones, Computers and CFL Bulbs) have been collected from different sources and sales of these items have been predictedfor future by polynomial regression analysis. The generated e-waste amount of these items in the future (up to year 2035) has been calculated based on End of Life (EOL) quantity with assumptions in their percentages, which is the same model concept used by the USEPA (USEPA, 2007, USEPA, 2008 and USEPA, 2009). Figure E.1 presents the methodology adopted in estimating the amount of e-wastes.

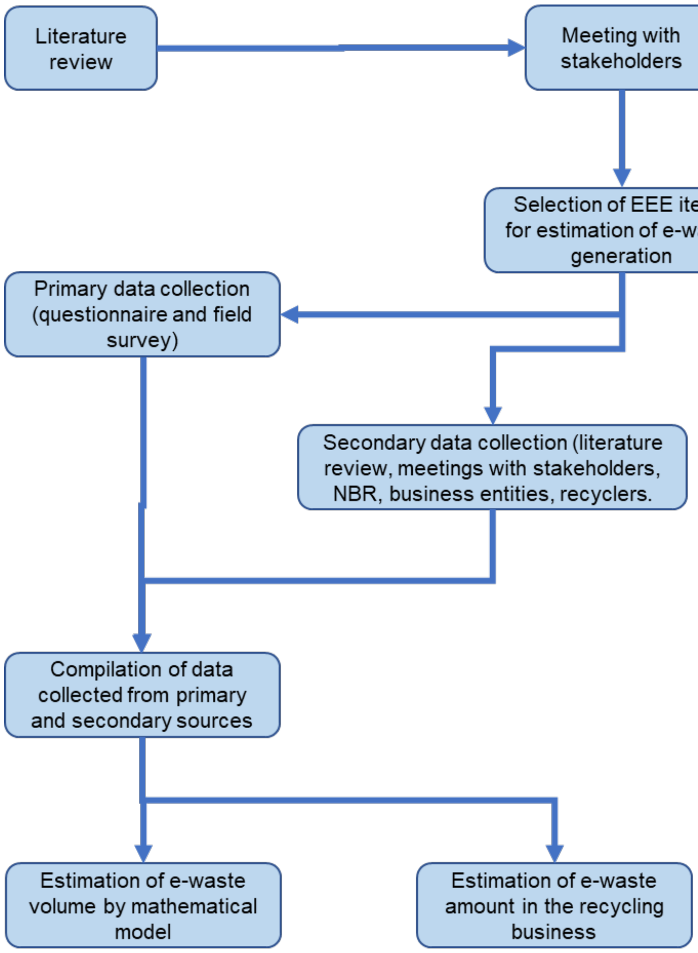


Figure E.1: Flow Chart showing the methodology adopted inE-waste Estimation

To assess the impacts of e-waste on human health, the present study has adopted two approaches.First approach is a direct one where questionnaire and field surveys has been conducted at the selected survey locations among the workersinvolved in the handling and recycling activities of e-wastes. In this approach, the objective was to find the awareness level of the workers about impacts of e-wastes and any health-related problems due to handling of e-wastes. The second approach is the health risk analysis of the exposed workers involved in this job through inhalation and ingestion of toxic chemicals. Risk analyses have been carried out following USEPA Guidelines (1989). The methodology adopted in assessing the impacts of e-wastes is shown in Figure E.2.

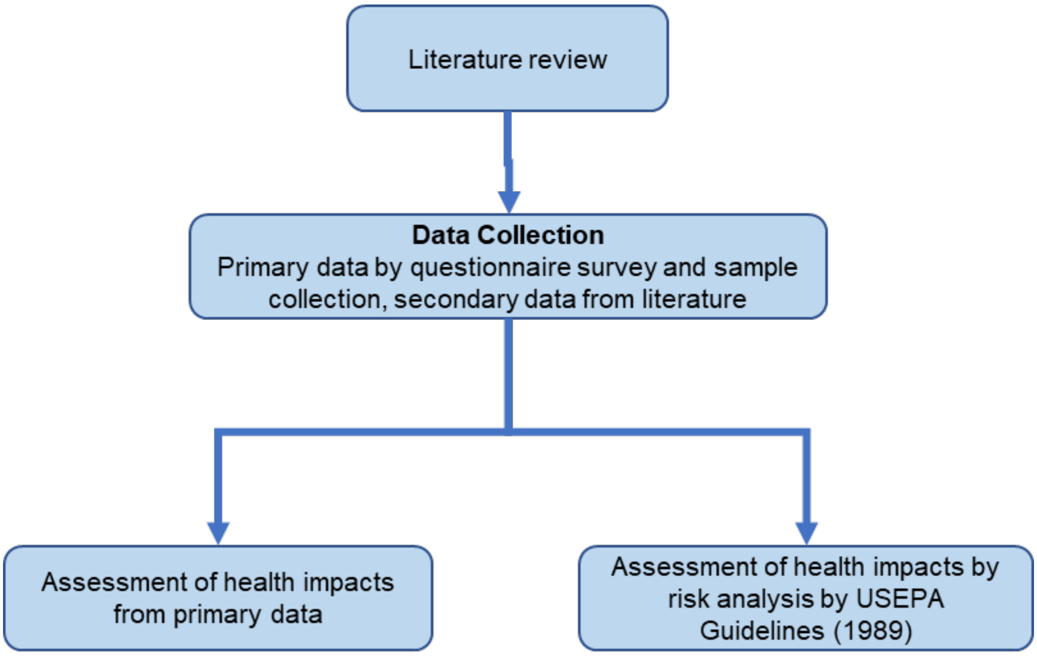


Figure E.2: Flow chart of Methods Adopted in Impact Assessment of E-Waste

To examine the potential of value metal recovery from e-wastes, hydrometallurgy process of extraction has been adopted. First, characterization of computer and cell phone's PCB and RAM of computer has been performed using AAS and XRF equipment. Then hydrometallurgical process was carried out to recover four value metals such as Gold, Silver, Copper and Tin from these items (Figure E.3).

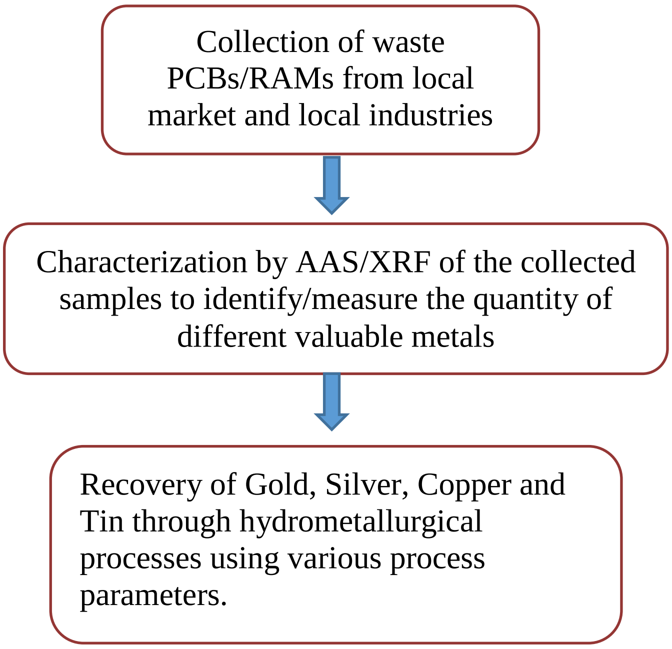


Figure E.3: Methodology for value metal recovery from e-waste

RESULT AND DISCUSSION

The present action research was undertaken with an objective of evaluating the existing data on the flow of e-wastes in Bangladesh and estimate the future trend of e-waste generation. Apart from this objective, it also aimed to assess the impacts of e-wastes on human health and environment and also investigate the resource recovery potential from e-wastes in an environmentally friendly way. Keeping these objectives in view, the research was designed and conducted accordingly. The outcomes of the research are discussed as follows:

Assessment of E-Waste Generation and Its Future Trend

To assess the amount of generation of e-wastes in Bangladesh and its future trend, the present study has adopted two approaches. The first approach is a mathematical model based on Material Flow Analysis (MFA). The model is based on the assumptions of the life span and past and future sales data for eight (Fan, TV, Air conditioner, Fridge, IT related equipment, Cell phones, Computers, CFL Bulbs) selected electronic products. The generated e-waste amount in the future is calculated following USEPA method (USEPA, 2009) based on EOL quantity with assumptions in their percentages. Using this model, the total e-wastes generated from eight selected items has been determined and is presented in Figure E.4.

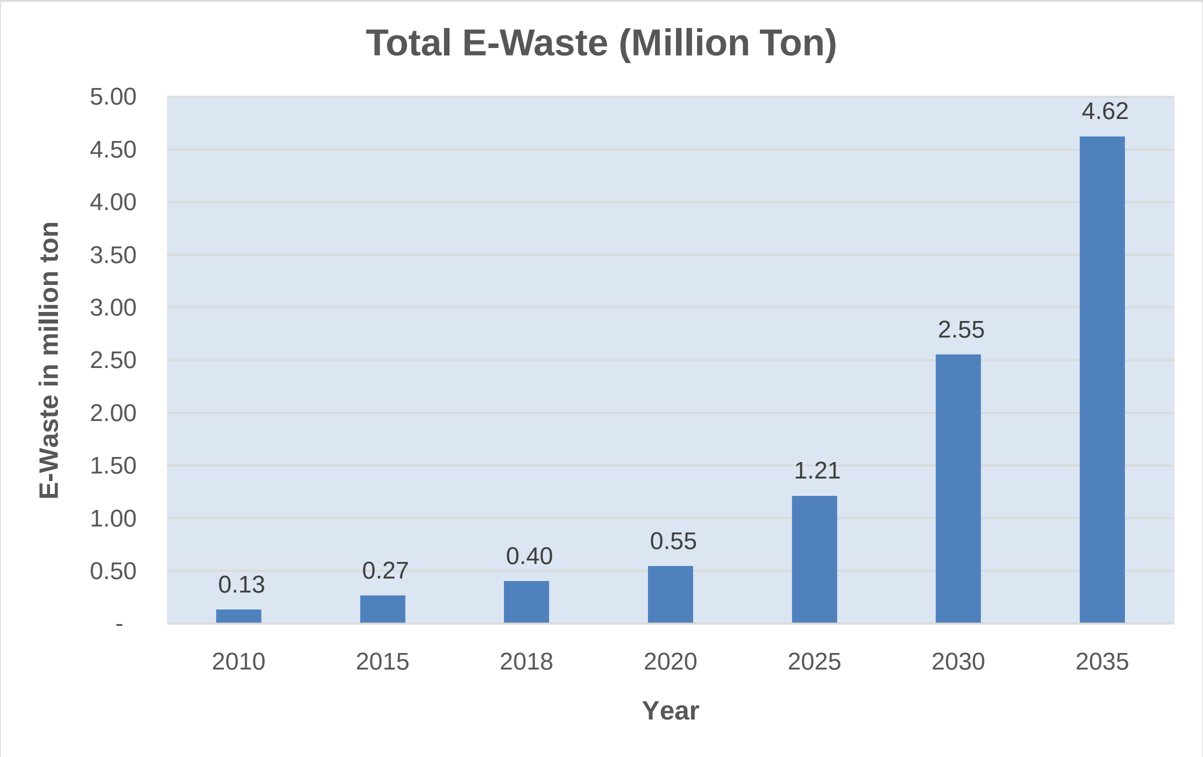


Figure E.4: Estimated amount of E-Wastes for Bangladesh up to year 2035

From this figure it is observed that at present (2018), amount of e-waste is 0.40 million ton and by year 2035 the amount will be 4.62 million ton with an annual growth rate of around 20%. The estimated figure appears to be realistic, judging from the fact that Bangladesh is undergoing a rapid growth in all sectors, especially very fast growth in the IT and mobile sectors. Moreover, the global modern-day manufacturing philosophy is to produce short life, low cost products and thereby contributing more wastes. According to the report of 'The Global E-Waste Monitor' (Balde et al., 2017), the world's total e-waste amount is 44.7 million ton in year 2016 among which 18.2 million ton is contributed by Asia (49 countries of Asia). Compared to the amount of China (7.21 million ton) and India (1.97 million ton) in year 2016, (Balde et. al, 2017) the estimation in the present study (0.31 million ton in year 2016) appears to be logical. Table E.1 shows a comparison of the estimated amount of e-wastes in year 2016 for Bangladesh in the present study along with the findings of previous studies.

Table E.1: Comparison of E-Wastes in Bangladesh among different Studiesfor year 2016

ESDO (2016)	Balde et. al. (2017)	Present Study (2018)
9.81 Million Ton	**0.142 Million Ton**	**0.31 Million Ton**

It has been observed from Table E.1 that the estimated amount in the three studies vary in a wide range. The difference between the findings of ESDO and those of the present study is mainly due to the difference in contribution from the Ship Recycling Industry. ESDO's study estimated a large amount of e-waste from Ship Recycling Industry (8.86 Million Ton) which is said to be illegal import. The present study did not find any such evidences and hence its estimation is based on consideration of only the amount found during the field visit. The basis of estimation by Balde et al. (2017) could not be known, therefore it will not be fair to make any comment on their value. It can only be said that the variation of e-wastes amounts between Baldeet. al (2017) and the present study is not so wide and many assumptions and approximations are involved in the estimation process, resulting in such variations. Another important factor is the availability and authenticity of data. Since there are no e-waste management system in Bangladesh and therefore there exists no database on amount of sale, consumption, recycling, export of EEE products. There are some other findings on e-wastes amount in Bangladesh but almost all of them considered one or two items (mainly mobile phones and computer), some are only for Dhaka and some are only for a specific year. Therefore, those data are not comparable to the data reviewed and analyzed under the present study.

The second estimation is based on primary data of generated e-wastes from different sources in Bangladesh. The total amount of e-wastes obtained from this approach is 0.0133 million ton/yr (Table E.2). A questionnaire survey was conducted only within a small area of concentrated e-wastes businesses of Dhaka City. Therefore, it does not show the whole picture of e-wastes businesses and the exact amount of e-wastes which are undergoing recycling could not be known. Moreover, the data from all the nine licensed recyclers and exporters could not be obtained, only a few recyclers provided their data. Therefore, the amount appears (0.0133 million ton/yr) much less compared to the amount estimated (0.40 million ton in year 2018) in approach 1 (mathematical model), based on sales data. It is worthy to mention here that all the e-wastes generated in Bangladesh do not enter into the formal and informal recycling businesses. Findings from existing literature, and those from this study show that only a small fraction of generated e-wastes enter into the recycling business and the rest end up at the landfill sites. The present study has found that only 3% of the generated e-wastes penetrate into the market for recycling and rest 97% e-wastes go to the landfill, mixed with municipal solid wastes which is very harmful for environment.

Table E.2: Total Amount of E-wastes in Recycling Sector

Source	Ship Recycling Industry	E-Waste Recycling Industry 1	E-Waste Recycling Industry 2	Bhangari Shops/Dealers	E-Waste Exporter	Universities/ Institutional Organizations
Average Amount of E-Waste (Ton/year)	4,000	1,146	700	6,217	1,000	220
Total		13,283 Ton/year (= 0.0133 Million Ton/year)				

Assessment of Impacts of E-Wastes

Inappropriate recycling of e-waste generates significant hazardous emissions, with severe impacts on health and environment.Health and safety risk associated with informal recycling process includes occupational health risks posed to e-waste collectors and handlers and community health risks posed to the surrounding community.In Bangladesh, e-wastes handling, dismantling and recycling are carried out in a rudimentary manner in the informal sector; no safety measures are adopted in carrying out these activities. Therefore, the workers are directly exposed to the risk of health hazards and the people are indirectly exposed to the risk of environmental (air, water, soil) pollution due to improper management and disposal of e-wastes.

Occupational and direct local exposure is the most evident scenario for the people associated with the e-waste collection and recycling process. To assess the impacts, two approaches were adopted in this study. At first,an attempt has been made to assess the impacts of e-wastes by conducting direct survey. The second approach is an indirect one, in which a risk analysishas been carried out to determine if the exposed workers are at risk by handling the e-wastes, using the USEPA Guidelines values.

Indirect approaches have been adopted to assess the impacts of e-wastes on human health, especially on the workers involved in activities like collection, dismantling, separation and resource recovery. A survey was conducted among the workers to understand the level of their awareness on the effects of e-wastes. It has been found from the survey that none of those workers are aware of the hazards and health risks associated with improper handling and recycling of e-wastes. Survey findings revealed that only 7% people know that e-wastes contain toxic chemicals, 24% reported dust emission, especially from processing of scanner, printer and photocopier, 9% know about acid contents of batteries, and 3% know that refrigerator contains toxic gas. Ten individuals out of 65 reported that they have experienced injuries (cut in hands, legs and head) while handling, dismantling and recycling of e-wastes. During the survey period, only one person was seen wearing a face musk while dismantling a fridge. A few workers complained about cold and other minor health related problems and they were not sure about the cause of these problems. It has been observed from the field survey that most of the workers involved in e-wastes recycling works are in their teens (average age 18 years). They work bare handed, bare footed, without any safety gears. The dermal contact of toxic chemicals poses a risk to their health. Again, continuous exposures

(8-12 hours daily) to e-wastes and inhalation of toxic gases from different activities in the workplace make them vulnerable to different diseases. Most of the times, e-wastes are kept in open air and there exists a good chance of leaching of toxic chemicals by rain and wind and they can easily get into the environment. Workplace injury is very common in handling, dismantling and recycling of e-wastes. It is evident that during the dismantling process and incident of injuries, workers come in direct contact of the hazardous elements in e -wastes and are exposed to associated risks, although they are neither aware of it, nor do appear to care about it.

The present study has undertaken another approach called 'Risk Analysis' to assess the impacts of e-wastes on the exposed population (workers). The aimof this analysis is to estimate the potential health risk to workers by ingestion and inhalation of contaminated water and air by toxic elements such as lead, cadmium and chromium. The relationship between the intensity of the pollutant and potential risks to human health is assessed by human health risk assessment methodology proposed by USEPA (1989). To assess the risk of the people associated with e-wastes handling and recycling, workers are classified in three age groups: i) W-A: workers below 15 years of age ii) W-B: Workers between 15-25 years of age and iii) W-C: Workers above 25 years of age. It is assumed that they are exposed to e-wastes around 10 hours per day and the exposure time is considered 300 days in a year.The risk analysis result shows that all age group of workers (including children and adult) are at carcinogenic and non-carcinogenic risks of health hazards through inhalation of toxic elements such as Cr and Pb (Table E.3 and E.4). Although the exposed workers' health is not at carcinogenic and non-carcinogenic risk through ingestion (water) of Cd and Cr(Table E.5, E.6 and E.7), but the workers are at carcinogenic risk of health hazards due to ingestion of lead (Pb)(Table E.8). It is noted here that due to the dearth the air quality data in the exposed working area, concentration of Pb, Cd and Crwere taken from a study on Trace metal Concentrations in Air of Dhaka City (Islam et al., 2015). Water and soil samples were collected from the surrounding area of the e-wastes recycling businesses and analyzed in the laboratory and used in the risk analysis through ingestion.

Table E.3: Carcinogenic Risk Factor (Chromium)

Concentration of Cr:9.08 ng/m^3 (Islam et al., 2015)

Medium: Air

Formula: Intake Rate, I = A × (C×CR×EF×ED)/(BW×AT)

Risk Factor, R = I ×SF

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (m^3/day)	Concentration, C (mg/m^3)	Absorption Percentage, A	Intake rate, I (mg/kg.day)	Inhalation Slope Factor $(mg/kg.day)^{-1}$ (Table 5.1)	Risk factor	Comment
W-A	35	10	300	365	30	9.08×10^{-6}	50	3.20×10^{-6}	41	1.31×10^{-4}	Unacceptable
W-B	50	10	300	365	30	9.08×10^{-6}	50	2.24×10^{-6}	41	9.18×10^{-5}	Unacceptable
W-C	60	10	300	365	30	9.08×10^{-6}	50	1.87×10^{-6}	41	7.67×10^{-5}	Unacceptable

Table E.4: Carcinogenic Risk Factor (Lead)

Concentration of Pb: 305.6 ng/m^3 (Islam et al., 2015)

Medium: Air

Formula: Intake Rate, I = A × (C×CR×EF×ED)/(BW×AT)

Risk Factor, R = I ×SF

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (m^3/day)	Concentration, C (mg/m^3)	Absorption (%), A	Intake rate, I (mg/kg.day)	Inhalation Slope Factor, SF (https://oehha.ca.gov/chemicals/lead-and-lead-compounds) $(mg/kg.day)^{-1}$	Risk factor (R)	Comment
W-A	35	10	300	365	30	305.6×10^{-6}	50	1.07×10^{-4}	4.2×10^{-2}	4.50×10^{-6}	Unacceptable
W-B	50	10	300	365	30	305.6×10^{-6}	50	7.54×10^{-5}	4.2×10^{-2}	3.17×10^{-6}	Unacceptable
W-C	60	10	300	365	30	305.6×10^{-6}	50	6.28×10^{-5}	4.2×10^{-2}	2.64×10^{-6}	Unacceptable

Table E.5:Non-Carcinogenic Risk Factor (Cadmium)

Concentration of Cd: 0.018 mg/L

Medium: Water

Formula: Intake Rate, I = (C*CR*EF*ED)/(BW*AT)

Hazard Quotient, HQ = I/RfD

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (L/day)	Concentration, C (mg/L)	Intake rate, I (mg/kg.day)	Oral Reference Dose Factor, *RfD* (mg/kg.day)	Hazard Quotient, HQ	Comment
W-A	**35**	**10**	**300**	**365**	**1**	**0.018**	**4.23×10^{-4}**	**5×10^{-4}**	**0.85 (< 1)**	**Safe**
W-B	**50**	**10**	**300**	**365**	**1**	**0.018**	**2.96×10^{-4}**	**5×10^{-4}**	**0.59 (<1)**	**Safe**
W-C	**60**	**10**	**300**	**365**	**1**	**0.018**	**2.47×10^{-4}**	**5×10^{-4}**	**0.49 (< 1)**	**Safe**

Table E.6:Non-Carcinogenic Risk Factor (Chromium)

Concentration of Cr: 0.015 mg/L

Medium: Water

Formula: Intake Rate, I = (C*CR*EF*ED)/(BW*AT)

Hazard Quotient, HQ = I/RfD

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (L/day)	Concentration, C (mg/L)	Intake rate, I (mg/kg.day)	Oral Reference Dose Factor, *RfD* (mg/kg.day)	Hazard Quotient, HQ	Comment
W-A	35	10	300	365	1	0.015	3.52×10^{-4}	0.003	0.12 (< 1)	Safe
W-B	50	10	300	365	1	0.015	2.47×10^{-4}	0.003	0.09 (<1)	Safe
W-C	60	10	300	365	1	0.015	2.05×10^{-4}	0.003	0.07 (<1)	Safe

Table E.7:Carcinogenic Risk Factor (Chromium)

Concentration of Cr: 0.015 mg/L

Medium: Water

Formula: Intake Rate, I = (C*CR*EF*ED)/(BW*AT)

Risk Factor, R = I ×SF

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (L/day)	Concentration, C (mg/L)	Intake rate, I (mg/kg.day)	Oral Slope Factor, SF (Table 5.1) $(mg/kg.day)^{-1}$	Risk factor	Comment
W-A	35	10	300	365	1	0.015	3.52×10^{-4}	0.5	1.76×10^{-4}	Acceptable
W-B	50	10	300	365	1	0.015	2.47×10^{-4}	0.5	1.24×10^{-4}	Acceptable
W-C	60	10	300	365	1	0.015	2.05×10^{-4}	0.5	1.03×10^{-4}	Acceptable

Table E.8:Carcinogenic Risk Factor (Lead)

Concentration of Pb: 0.063 mg/L

Medium: Water

Formula: Intake Rate, I = (C*CR*EF*ED)/(BW*AT)

Risk Factor, R = I ×SF

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (L/day)	Concentration, C (mg/L)	Intake rate, I (mg/kg.day)	Oral Slope Factor, SF (https://oehha.ca.gov/chemicals/lead-and-lead-compounds) $(mg/kg.day)^{-1}$	Risk factor	Comment
W-A	35	10	300	365	1	0.063	1.48×10^{-3}	8.5×10^{-3}	1.26×10^{-5}	Unacceptable
W-B	50	10	300	365	1	0.063	1.04×10^{-3}	8.5×10^{-3}	8.84×10^{-6}	Unacceptable
W-C	60	10	300	365	1	0.063	8.63×10^{-4}	8.5×10^{-3}	7.73×10^{-6}	Unacceptable

There is a possibility of workers being exposed to health risksfrom dermal contact of the hazardous elements in e-wastes. Due to the absence of required data, any analysis to assess this possibility could not be performed. Again, the present study could not find any scientific papers or supporting documents to support the risks posed by dermal contact of the toxic elements.

In Bangladesh, mainly in Dhaka city, open burning of wires/cables to recover copper is exercised by informal sector. This burning activity produces harmful toxic compounds like dioxin and furan and causes air pollution. The e-waste recycling activities are mainly concentrated in old parts of Dhaka (Islambag, Nimtoli, Chankharpool, Waizghat, Kamrangir Char).Apart from e-wastes, a good number of different types of small factories, and specially tannery industries were located in these areas till 2016, and therefore it is very difficult to say that the pollution of heavy metals is solely contributed by e-wastes. Other than recovery and recycling, a considerable amount of e-wastes are mixed with the domestic solid wastes and are ended up in the landfill.Weathering actions and chemical reactions accelerate leaching of hazardous elements from e-wastes and release those in air, water and soil and thus pose a serious threat to the environment.Atmospheric pollution due to open burning and dismantling activities pose a risk to the surrounding locality as well as to remote areas. This environmental pollution serves as a crucial source of food chain contamination as contaminantsmay accumulate in aquatic lives, agricultural lands, poultry and livestock.

Resource Recovery Potential of E-Waste

E-waste is often called as urban mine as it contains several precious metals (Au, Ag, Pt, Pd, Nd etc.) along with hazardous metals. If recovery of these precious metals can be performed efficiently in an environmentally friendly way, e-waste no longer remains a waste, rather it turns into a resource. In fact, recovery of value metals from e-wastes is more efficient than mining of such metals from ores. The present action-based research project has attempted to recover a number of value metals such as gold, silver, copper and tin from printed circuit board (PCB) of cell phones and computers and computer RAMs. The presence of different elements including the value metals are identified by XRF, SEM and AAS analysis and is presented in Table E.9. It is noted here that the concentration of various elements present (Table E.9) in tested PCBs/RAMs varied in a wide range and the reason behind this variation is that the contents of PCBs vary from manufacturer to manufacturer, even with the variation in model types.

Table E.9: Amount of element present in different types of mobile PCB, Computer PCB and RAM

Elements	Concentration (mg/L)					Concentration (%wt.)
	Nokia PCB	Chinese PCB	Mobile PCB+ HNO_3	Computer PCB	RAM	Metal powder of Recycler 1
Aluminum	746	753		699		0.68
Arsenic	<0.05	<0.05				--
Calcium	149	79.9	28.7	233	113.8	0.66
Cadmium	<0.01	0.18	<0.05	<0.02	<0.05	--
Chromium	266	278	6.5	957	4.39	0.02
Cobalt	32.5	9.04	28.4	28.7	48.1	--
Copper	25575	12825	18800	29450	66100	85.51
Iron	895	1528	4352	80700	4983	0.68
Lead	44	193	1270	12.8	600	3.24
Manganese	42.4	33.4	36.4	780	37.8	--
Mercury	<0.01	1.67	6.29	0.56	0.533	--
Molybdenum	14.2	3.59		85.8		--
Nickel	2263	733	3946	1175	3455	--
Silver	13.8	33.3	15.3	37.1	1.45	--
Tin	1835	1150		19480		3.44
**Gold concentration in the solution could not be determined due to lack of the appropriate radiation source in the testing equipment.						

To recover the value metals, a series of laboratory experiments and analyses were carried out following different routes to make the recovery more efficient and effective. The present study has adopted hydrometallurgy method over pyrometallurgy to recover the value metals since hydrometallurgical process has less environmental hazards, has high selectivity towards individual metals, and is more feasible for all metals and their alloys compared to the pyrometallurgical process. Laboratory test results of value metal recovery have demonstrated an efficient recovery of these metals (Silver >94%, Copper >99%, Tin >86%) and shown a promising potential of recovery of precious metals for Bangladesh. Gold recovery was performed using the latest environment friendly technique and showed significant amount of recovery, about 600 gm per ton of waste PCB. Table E.10 shows a comparison of recovered metal from 1 tonne of e-waste found in the present study and among the previous studies.

Table E.10: Comparison of yield value from experiment with reference value

Recovered Metal	1 ton PCBs/RAMs (present study)	1 ton PCBs/RAMs (Reference value)	Market Value (USD/gm)	Value Recovered (USD)
Gold	600 gm	279.93 gm (Vidyadhar, 2016) 1000 gm (Bidini et al. 2015)	38	$22,800
Silver	7.6 kg	7.2 kg (Bidini et al. 2015)	0.46	$3496
Copper	136.35 kg	190.512 kg (Vidyadhar, 2016)	0.01	$1363
Tin	24 kg	30.84 kg (Vidyadhar, 2016)	0.03	$720

It has been found from this study that every year licensed recyclers and exporters export from Bangladesh a significant amount of e-wastes, mainly used high-grade PCB and obsolete Telecom equipment which are rich in value metals to developed countries such as Singapore and Japan where they have facilities to recover precious metals from these e-wastes. Again, a considerable amount of e-wastes is disposed of in the landfills, thus polluting the environment and wasting the resources within it. Availability of a proper e-waste management and resource recovery system in Bangladesh could have made it possible to recover the value metals from the e-waste and add value to its economy. Given the right environment in terms of policy support, financial incentives and infrastructure facility and technology, recovery of resources from e-wastes can potentially lead to the development of a new industrial sector and thus enhance the growth of the country.

CONCLUSIONS

The major conclusions drawn from this research are as follows:

- The estimated amount of e-wastes is 0.40 million ton in 2018 and 4.62 million ton by 2035
- The growth rate of e-waste generation per year is around 20%
- Approximately 0.0133 million ton e-wastes enter into the recycling businesses every year
- The workers involved in e-wastes handling, dismantling and recycling are at risk of carcinogenic and non-carcinogenic health hazards through inhalation of toxic elements such as lead, cadmium and chromium

- Workers are exposed to carcinogenic health risk due to lead poisoning through ingestion. However, chromium and cadmium do not pose any health risks through ingestion
- The awareness level among the workers regarding the health impacts of e-wastes is quite low, almost non-existent.
- Workers, especially children in informal sector, carry out their recycling jobs without any safety measures or protective gears.
- Improper recycling and disposal of e-wastes pose risk to the environment. Weathering actions and chemical reactions accelerate leaching of hazardous elements from e-wastes and release those in air, water and soil and thereby pose a serious threat to the environment.
- Presence of different elements including value metals such as gold, silver, copper, tin, zinc etc and toxic metals such as arsenic, mercury, lead and chromium from printed circuit boards (PCB) of cell phones and computers and computer RAMs were ascertainedby XRF, SEM and AAS analysis. The concentration of various elements varied in a wide range.
- Efficient recovery of silver >94%, Copper >99%, Tin >86% through hydrometallurgical processes was achieved. Gold recovery [600 gm/per ton of waste PCBs/RAMS] using the latest environment friendly technique showed a promising potential of recovery of precious metals for Bangladesh.

RECOMMENDATIONS

Based on the research findings and discussions, following recommendations are made.

- Draft E-Waste Management Rule 2017 should be promulgated soon.
- Inventory and database of e-wastes (at least for selected items) should be established
- Separate collection, processing, recycling, recovery and disposal facilities should be established for proper e-waste management
- Awareness raising campaign among the consumers (through poster, leaflets, brochures, Radio-TV advertisements) should be given priority to make collection system effective
- Draft E-Waste Management Guidelines, 2016 should be finalized with consultation with the relevant stakeholders.
- Health and safety of the workers should be ensured in recycling process
- Government may consider offering incentives to the industrialists and entrepreneurs to come forward to set up recycling and recovery plants and thus facilitate the sustainable development mechanisms in the country.

ABBREVIATION

AAS	Atomic Absorption Spectroscopy
ARF	Advanced Recycling Fees
BAT	Best Available Technology
BBS	Bangladesh Bureau of Statistics
BCS	Bangladesh Computer Samity
BDT	Bangladeshi Taka
BEMMA	Bangladesh Electrical Merchandise Manufacturers' Association
BM	Base Metals
BMPIA	Bangladesh Mobile Phone Importers' Association
CFC	Chlorofluoro Carbon
CEE	Centre for Environment Education
CERM	Centre for Environmental and Resource Management
CRT	Cathode Ray Tube
DoE	Department of Environment
DMA	Dimethyl Acetamide
DREAL	Directions Régionales de l'Environnement, de l'Aménagement et du Logement
ECR	Environmental Conservation Rule
EDS	Electron Dispersion Spectroscopy
EEE	Electrical and Electronic Equipment
EMS	Environmental Management System
EOL	End of Life
EPR	Extended Producer Responsibility
ERP	European Recycling Platform
ESDO	Environment and Social Development Organization
HDD	Hard Disk Drive
ICT	Information & Communication Technology
IFC	International Finance Corporation
MFA	Material Flow Analysis

MSWM	Municipal Solid Waste Management
NBR	National Board of Revenue
PAH	Polycyclic Aromatic Hydrocarbons
PBDE	Polybrominated Diphenyl Ether
PC	Personal Computer
PCB	Printed Circuit Board
PM	Precious Metals
POP	Persistent Organic Pollutants
RAM	Random Access Memory
TOR	Terms of Reference
UNEP	United Nations Environment Programme
USD	United States Dollar
USEPA	United States Environmental Protection Agency
WEEE	Waste Electrical and Electronic Equipment
XRF	X-Ray Fluorescence Spectroscopy

Chapter 1

Introduction

1.1 INTRODUCTION

Last few decades have witnessed a phenomenal rise in the use of electronic components and micro-chips in household appliances, office equipment, transport systems and industrial tools and devices. As these items reach end of their lifecycle, they are ending up in increasing volumes in various dump sites in almost every country of the world.Wastes generated from these electronic components or electronic waste (e-waste) is currently the fastest growing global waste stream,with approximately 41.8 million tons of e-waste generated in 2014 alone. This amount is expected to be 49.8 million tons in 2018 with an annual growth rate of 4-5 percent (The Balance, 2018).

Bangladesh, in conformity with the global trend and due to its ongoing rapid growth, is also using electronics-based appliances, equipment and tools at an increasing rate, in people's homes, offices, industrial unit, vehicles and communication systems. This has caused a corresponding increase in the rate of generation of e-waste.Apart from the e-waste of its own generation, Bangladesh and several other developing nations in Asia and Africa (e.g. India, China, Pakistan and Nigeria) have become the dumping grounds for e-waste from the developed nations through legal and/or illegal trade routes (ESDO, 2011), further aggravating the situation for these nations.Bangladesh has in particular become the preferred choice as a 'burial ground' for ships at the end of their lifecycles; almost 60% of world's scrapped large and medium-sized ships end up at the shores of this country (ESDO, 2011). The engines, control mechanisms, heating, cooling, refrigeration and ventilation systems, and various otherequipment of these ships contain a significant amount of electronics and related items based on micro-chips. Some of these ships have even been found to carry toxic substances as their cargo. All these wastes add up to the already large amount of e-waste and other toxic substances being released into the environment in an unregulated manner.

The wastes generated from the obsolete electronic devices (E-Waste) or Waste from Electrical and Electronic Equipment (WEEE) can contain up to 1,000 different toxic substances, including lead, chromium and plastic additives, posing a serious health risk to the population. E-waste also contains a number of precious metals and other reusable materials such as plastics, and their recovery is a growing industry all over the world. However, recycling of electronic components is an extremely labor-intensive process and Bangladesh,being labor–abundant, has become a lucrative channel for processing e-waste. Apart from low-cost labor, lack of any regulation related to handling, processing and disposal of e-waste also makes countries like Bangladesh an attractive destination for e-waste dumping. As an example, it costs approximately $20 to recycle a PC in the United Sates (and other developed countries), while it is only $2 for the same process in Bangladesh (ESDO, 2011).

Around 20 to 30 per cent of electrical goods are recycled in Bangladesh by the informal sector and the rest is released in to landfills, rivers, ponds, drains, lakes, channels and open spaces (Riyad et al., 2014). Crude forms of dismantling often lead to toxic emissions, which pollute the environment and expose the workers to harmful materials. E-waste has a direct and visible impact on people's health, environment and livelihoods and is considered to be an unregulated domain. Understanding and proper management of e-waste is a stated item of the global Sustainable Development Goals (SDG) campaign, fulfilment of which is a nationally adopted commitment of Bangladesh.A better understanding and availability of reliable data on e-wastes will help achievement of several goals (Goals 3, 6, 11, 12 and 14) of Agenda for Sustainable Development by 2030. As such, finalization of the Draft the E-Waste Management Rules, 2017and its promulgation as an act have become a priority to the Government of Bangladesh. It attaches adequate importance to this issue of national and global concern and has already formulated National 3R (Reduce, Reuse & Recycle) Strategy, where e-waste issues have been addressed. The Department of Environment (DOE), under the overall policy directive of the Government, is undertaking various steps towards fulfilment of its commitment and this study is a part of this initiative.

Proper management of e-waste is also important considering the economic value of resources in the e-waste stream. The total value of materials present in e-wastes is estimated to be approximately EUR 55 billion in 2016 (Balde et al., 2017). As such, an effective policy for e-waste management and a mechanism for its implementation and monitoring will benefit Bangladesh in several direct and indirect ways, socially, environmentally and economically.

1.2 OBJECTIVES OF THE RESEARCH PROJECT

With this perspective in view, the three main objectives of the present study are:

(i) to estimate the amount of e-wastes generated in Bangladesh and to establish its future trend,

(ii) to assess its impacts on human health and environment and

(iii) to examine the potential of value metal recovery from e-wastes for Bangladesh. The specific objectives are shown below:

1.3 SCOPE OF THE RESEARCH

The scope of this action - based research project are as follows:

- Critical evaluation of available existing data in the past studies and researches on e-wastes amount in Bangladesh;
- Characterization of the major components of e-wastes in Bangladesh;
- Identification of the hazardous elements in the wastes and assessing its impacts on environment and human health;
- Estimation of the volume of wastes being generated annually including a prediction of future trend in generation and the value/recoverable/reusable material content in the waste stream;
- Examination of the current practice of e-waste management (collection, segregation, recycling, disposal, and monitoring of such wastes) in Bangladesh in the light of current practice of e-waste management in developed countries and
- Recommendation of a complete plan for recovery of some valuemetals from e-waste.

To achieve the objectives stated above, primary and secondary data on generation, transportation, disposal and collection of e-wastes have been collected by questionnaire survey, filed visits, interviews and formal and informal meetings with the stakeholders. Mathematical models have been applied to estimate the amount of e-wastes and risk analyses has been carried out to assess its impacts on human health. Characterization of e-wastes has been performed by analyzing the collected e-wastes samples in the laboratory. A series of laboratory experiments has been conducted to investigate the potential of value metal recovery from e-wastes.

1.4 THE RESEARCH TEAM

Keeping in view of the wide scope of work, a six-member research team has been formed. The team leader and first principal investigator of the team is Dr. Rowshan Mamtaz, Director, Centre for Environmental and Resource Management (CERM) and Professor, Department of Civil Engineering, BUET. Dr. FahmidaGulshan, Professor, Department of Materials and Metallurgical Engineering, BUET is the second principal investigator of the team. Apart from these two principal investigators, four Research Assistants: Shuvo Ahmed, Imran Noor, Sumaiya Rahman and Prithvi Shams (graduate students of BUET from Environmental Engineering and Materials and Metallurgical Engineering background) have been included in the team to facilitate the work.

1.5 ORGANISATION OF THE REPORT

This report is comprised of eight chapters and a list of references and annexure.

Chapter 1: Introduction provides the background of the project, its objectives and scope of the research.

Chapter 2: Review of Literaturepresents the relevant literature and information on e-waste, its composition, generation, impacts on human health and environment and metallurgical processes of resource recovery in detail. It also encompasses the e-waste management system and legislation that currently exists in Bangladesh and in the developed countries.

Chapter 3: Methodology describes the methods adopted in achieving the objectives of this research project.

Chapter 4: Assessment of Generation of E-Wastes presents an estimation of amounts of e-wastes in Bangladesh and establishes its future trend.

Chapter 5: Assessment of Impacts of E-Wasteinvestigates the impacts of e-wastes on human health and environment by direct survey and risk analysis.

Chapter 6: Value Metal Recovery from E-Waste presents a laboratory demonstration of recovery of value metals such as Gold, Silver, Copper and Tin from used PCBs and RAM along with their characterization.

Chapter 7:Discussion provides a detail analysis and discussion on the results obtained from filed visits, laboratory tests, and numerical analyses.

Chapter 8: Conclusion presents the main findings of the research project. It also includes a number of recommendations put forward by the research team for an effective and sustainable e-waste management systemincluding its implementation and monitoring.

Chapter 2

Literature Review

2.1 E-WASTE: AN INTRODUCTION

E-Waste is a generic term embracing various forms of electrical and electronic equipment that have ceased to be of any use to their owners. E-Waste is unwanted, broken, obsolete and discarded electronic equipment. The equipment includes a broad range of electronic devices from large household appliances such as refrigerators, air-conditioners, washing machines to small devices such as hand-held cellular phones, personal stereos, VCRs, DVD players, consumer electronics, computers, computers peripherals etc. (Figure 2.1 and Figure 2.2). Once these products reach at the end of their useful life they are called e waste from electrical and electronic equipment (WEEE). According to Step Initiative (2014), "E-waste is a term used to cover items of all types of electrical and electronic equipment (EEE) and its part that have been discarded by the owner as waste without intention of re-use."

Figure 2.1: Dumped E-Waste

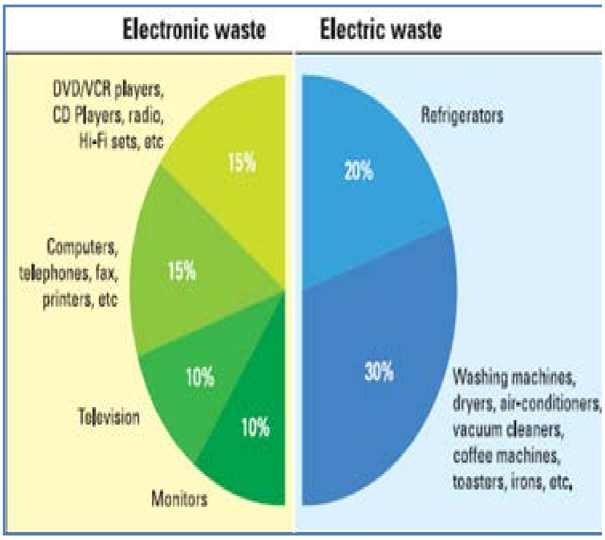


Figure 2.2: Items of WEEE

E-waste is one of the fastest growing solid waste streams around today. According to a study conducted by European Union, e-waste is growing at a rate of 3.0 – 5.0% per annum or approximately three times faster than other individual waste streams in the solid waste sector (Schwarzer et al. 2005). Rapid uptake of information technology around the world coupled with the advent of new design and technology at regular intervals in the electronics sector is causing the early obsolescence of many electronic items used around the world today.

According to the EU's revised directive on WEEE, e-waste can be categorized as in Table 2.1.

Table 2.1: Categories of E-Waste (Herat and Agamuthu, 2012)

E-waste category	Some examples of products
Temperature exchange equipment	Refrigerators, freezers, air conditioning equipment, dehumidifying equipment, heat pumps, radiator containing oil and other temperature-exchange equipment
Display equipment that have a surface greater than 100 cm^2	Screens, televisions, LCD photo frames, monitors, laptops and notebooks
Lamps	Straight fluorescent lamps, compact fluorescent lamps, high density discharge lamps, low pressure sodium lamps, LED
Large equipment (any external dimension greater than 50 cm)	Washing machine, dishwashing machine, clothes dryer, cooker, electric stove, electric hot plate, musical equipment, large printing machines, copying equipment, large medical devices, etc.
Small equipment (no external dimension greater than 50 cm)	Vacuum cleaner, carpet sweeper, microwaves, iron, toaster, electric knives, electric kettles, electric shavers, scales, calculators, radio sets, video cameras, video recorders, hi-fi equipment, toys, smoke detectors, etc.
Small IT equipment (no external dimension greater than 50 cm)	Mobile phones, GPS, pocket calculators, routers, personal computers, printers, telephones

2.2 COMPOSITION OF E-WASTE

E-waste is made up of a diverse range of materials, that can be toxic and also of high value, difficult to give a generalized material composition for the entire waste stream. However, most studies examine five categories of materials: ferrous metals, non-ferrous metals, glass, plastics and others (Figure 2.3). While bulk materials like iron, aluminum, plastic and glass account for over 80% of wt., valuable and toxic materials are found in smaller quantities but are still of high importance. The material composition of different appliances is often similar but the percentage of different components varies a lot. The main and most common substances found in e waste is shown in Table 2.2.

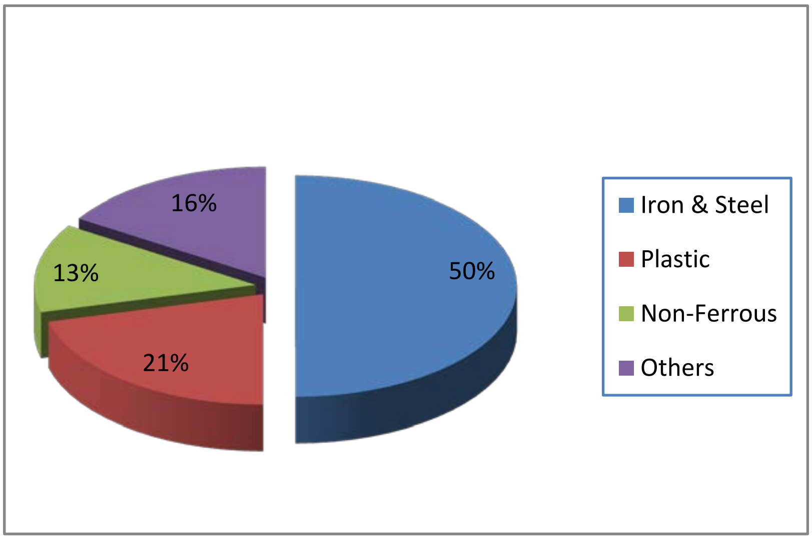


Figure 2.3: Material Composition in E-Waste

Table 2.2: Main Compounds Commonly Found in E-Waste (Hagelüken 2006)

Category	Compounds
Precious metals	Gold (Au), Silver (Ag), Palladium (Pd), and to a lesser extent Platinum (Pt)
Base metals	Copper (Cu), Aluminum (Al), Nickel (Ni), Tin (Sn), Zinc (Zn), Iron (Fe)
Metals (toxic) of concern	Mercury (Hg), Beryllium (Be), Indium (In), Lead (Pb), Cadmium (Cd), Arsenic (As), Antimony (Sb
Halogens	Bromine (Br), Fluorine (F), Chlorine (Cl)
Combustibles	Plastic and organic fluids

Regardless of the particular type of electronic component concerned, all e-wastes can be broken down to a bunch of specific metals, polymers and glass (Figure 2.4).

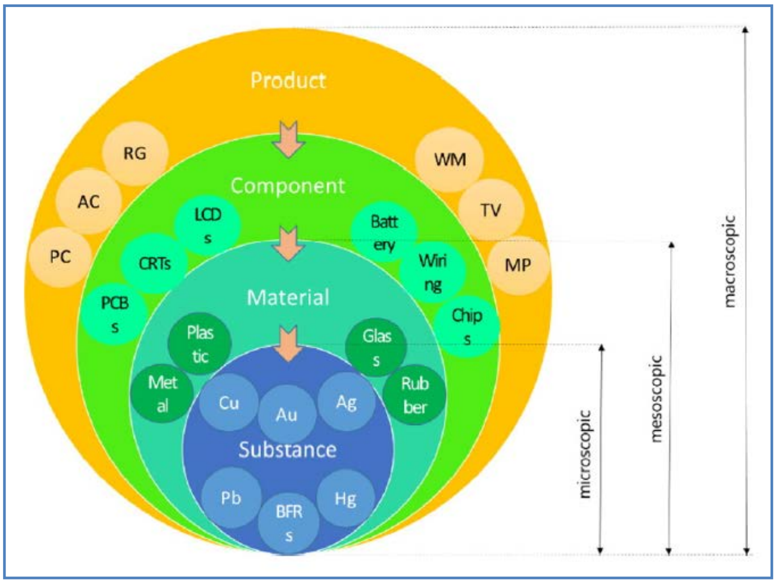


Figure 2.4: Elemental Composition of E-Waste (Zeng et al., 2017)

Various types of elements found in different components of electrical and electronic equipment are shown in Table2.3.

Table 2.3: Metal Contents in Various Components of E-Waste

Item	Component	Hazardous Elements	Rare Earth Metals	Value Metals
TV, PC Monitors	CRTs	Pb, Ba, Hg, Cd, Sb		
	Flat Screen	Hg, Sb	Y, Eu, La, Ce, Tb, Gd, Pr, In	Ag, Au, Pd
Personal Computer/ Laptop/ Telecom Servers	PCBs	Be, Pb, Hg, Brominated Flame Retardants, Sb		Au, Ag, Pd
	Floppy disks			Cr
	Hard Drives	Pb	Nd, Pr, Dy	Ag, Au, Pt, Pd, Rh, Ru,
	Capacitors	Pb	Ta	
	Connectors	Be		
	Batteries	Hg, Pb		Co, Li, Mn, Ni
Cell Phone	PCBs	Pb, Hg		Ag, Au, Pd
	Batteries			Li, Co, Mn, Ni
	Speaker Magnet		Nd, Pr	
Freezers, Washing Machine		Hg		
Printer		Pb		
	Laser Printer	Pb, Be		

Item	Component	Hazardous Elements	Rare Earth Metals	Value Metals
Chip resistors and Semiconductors		Cd		
LED Light			In, Eu, Y, Gd, Ce	Ga, Al, Cu
CFL Bulb		Hg, Pb		
		Hg, Cd, Pb		Ni, Al
Common Source	Batteries	Pb		Sn
	Solder	Cd, Sb		Cu
	Cabling	Be, Hg		
	Switches	BPA, DPB, Pythalates		
	Plastics	PVC, PCB, Pb		
	Transformer & capacitors	Sb		
	IC			

Toxic substances and other harmful substances are usually concentrated in printed circuit boards (PCB) and Cathode Ray Tube(CRT). The metal flows split into ferrous metals (the second largest group of the whole system), Al, Cu and mixed and precious metals. It has been found from a study (Suvesh, 2007), that a computer of an average wt. of 31.5 kg contains a number of toxic elements (Table 2.4).

Table 2.4: Composition of Toxic Elements in a Computer (Suvesh, 2007)

Elements	Quantity
Plastic	7.24 kg
Lead	1.98 kg
Mercury	0.693 g
Arsenic	0.4095 g
Cadmium	2.961 g
Chromium	1.98 g
Barium	9.92 g
Beryllium	4.94 g

Metal extraction from e-waste is more efficient than from ores. Ore is not homogeneous in their precious metal content, and very few ores can be classified as high grade. Extraction from these ores is achieved in a multitude of steps, with material losses occurring in each successive step. Ore processing is also very toxic for the environment. In contrast, metal extraction from e-waste is simpler and requires very few steps as most of the precious metals exist in elemental forms. Table 2.5 provides a comparison of metal extraction efficiency from discarded electronics and typical ores. Because of the presence of a number of value metals, e -waste is often called urban mine.

Table 2.5: Metal Concentration in Electronics and Ore (Desjardins, 2014; Investing News Network, 2016; McLeod, 2014; Namias, 2013; Vincic, 2015)

	Item	Copper (%wt.)	Silver(ppm)	Gold(ppm)	Palladium(ppm)
EEE	Television board	10	280	20	10
	PC board	20	1000	250	110
	Mobile phone	13	3500	340	130
	Portable audio scrap	21	150	10	4
	DVD Player scrap	5	115	15	4
	Avg. electronics	13.8	1009	127	51.6
Ore/mine		0.6	215.5	1.01	2.7

It has been reported in several studies that 1 tonne of phone handsets contains 3.5kg of Ag, 340 g Au, 140g of Pd and 130 kg of Cu. Gold content of total e-waste generated in 2014 is roughly 300 tonnes, which represents 11% of the global gold production from mines in 2013.1 tonne of e-waste from personal computers contains more gold that can be recovered from 17 t of gold ore (Khaliq et al., 2014).

2.3 GENERATION OF E-WASTE

2.3.1 World Scenario

In today's world, e -waste is the fastest growing waste stream. The main source of e-waste generation are imports of electrical and electronic equipment, government, public and private sector, discards, secondary markets of old PCs, phones, and individual households. Three categories of e waste consist of almost 90% of e-waste. Among them large household appliance accounts 42.1%, information and communication technology equipment cover 33.9% and consumer electronics accounts for 33.7% (Cleanup, 2009).

The growing amount of e-waste is the result of several trends. The global information society is growing at great speed. It is characterized by an increasing number of users and rapid technological advances that are driving innovation, efficiency, social and economic development. Many people own more than one information and communication technology (ICT) device, and replacement cycles for mobile phones and computers, and also for other devices and equipment, are becoming shorter. At the same time, disposable incomes in many developing countries are increasing and a growing global middle-class is able to spend more on electrical and electronic equipment, consequently generating more e-waste. Current trends suggest that the amount of e-waste generation will increase substantially over the next decades, and that better data to track these developments are needed. Estimation of E-waste generation is made from 44.7 Million Metric Ton in year 2014 to50 Million Metric Ton in 2018 (Cuchiella et al, 2015).

Technological advancements and growing consumer demand have defined the era in which electronics have become a prominent part of the waste stream. The global quantity of electronic waste in 2014 was mainly comprised of 12.8 million metric tons of small equipment, 11.8 million metric tons of large equipment and 7 million metric tons of temperature exchange equipment (including cooling and freezing equipment) (Kumar et al., 2017). The amount of e-waste is expected to grow to almost 50 million metric tons in total by 2018, with a growth rate of 4 to 5 percent year-to-year (Statista 2018). The global quantity of e-waste generation in 2016 was around 44.7 million metric tons (Mt)or 6.1 kg per inhabitant. It is estimated that in 2017, the world e-waste generation will exceed 46 Mt. The amount of e-waste is expected to grow to 52.2 Mt in 2021, with an annual growth rate of 3 to 4% (Balde et al, 2017). Figure 2.5 shows the generated and estimated e-waste globally.

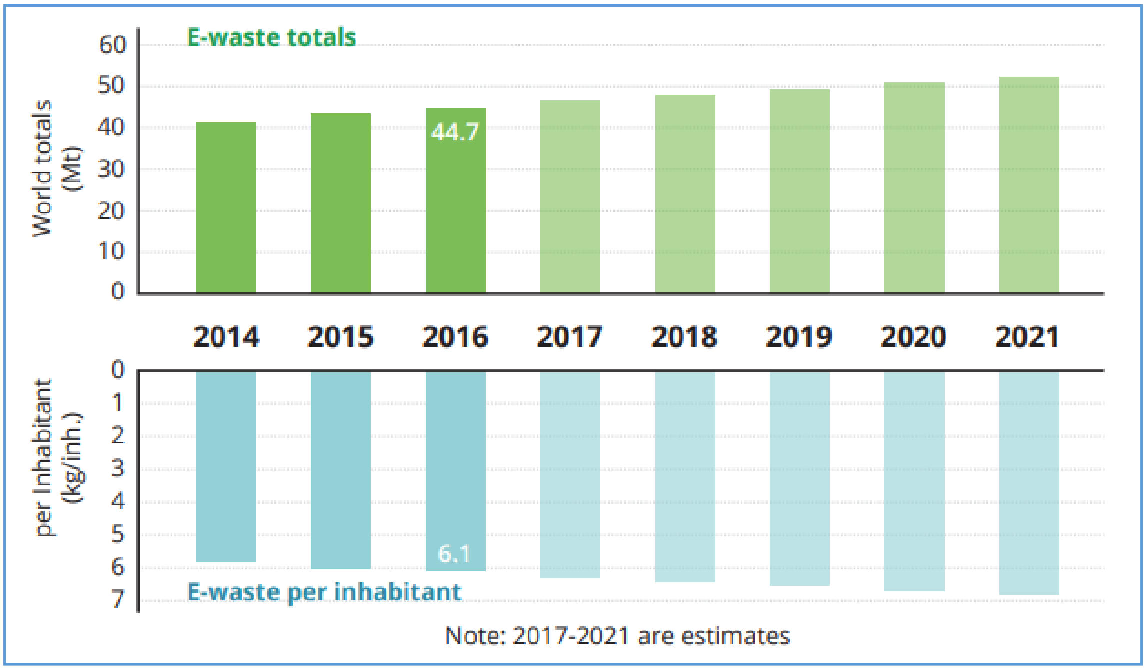


Figure 2.5: Global Generation of E-Waste (Balde et al, 2017)

Asia generates the greatest amounts of e-waste; Africa the least, both in total and per inhabitant (Balde et al., 2017).In 2016, Asia was the region that generated by far the largest amount of e-waste (18.2 Mt), followed by Europe (12.3 Mt), the Americas (11.3 Mt), Africa (2.2 Mt), and Oceania (0.7 Mt). While the smallest in terms of total e-waste generated, Oceania was the highest generator of e-waste per inhabitant (17.3 kg/inh), with only 6% of e-waste documented to be collected and recycled. Europe is the second largest generator of e-waste per inhabitant with an average of 16.6 kg/inh; however, Europe has the highest collection rate (35%). The Americas generate 11.6 kg/inh and collect only 17% of the e-waste generated in the countries, which is comparable to the collection rate in Asia (15%) (Figure 2.6). However, Asia generates less e-waste per inhabitant (4,2 kg/inh). Africa generates only 1.9 kg/inh and little information is available on its collection rate (Balde et al, 2017).

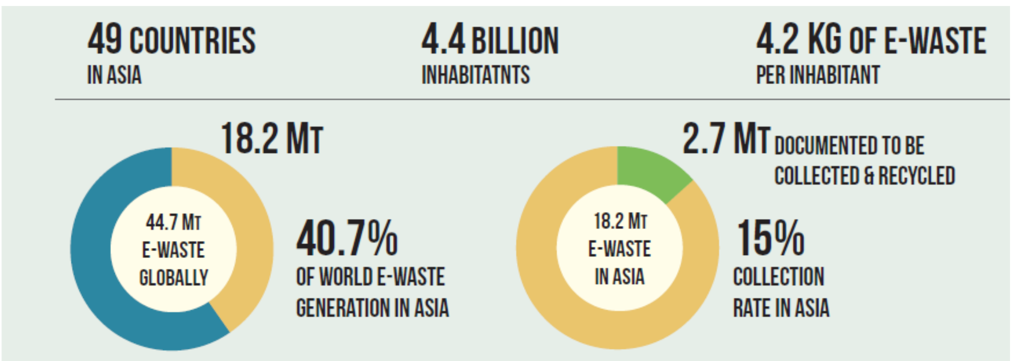


Figure 2.6: Generation of E-Waste in Asia (Balde et al, 2017)

2.3.2 Bangladesh Scenario

In recent years, as a result of the rapid growth of the economy and fast-growing access to technology, a market has emerged for computers, electrics and home appliances. According to the global trend, the market for electronic goods in Bangladesh is having an exponential growth due to the rising disposable income and increasing demand for the latest electronics products. No comprehensive study on the amount of generation of total e-wastes has been conducted so far in Bangladesh. However, few studies were carried out in small scale and location and item specific to estimate the generation of e-waste. According to Bangladesh Electrical Merchandise Manufactures Association (BEMMA), Bangladesh consumes around 3.2 million of electronics products each year (Yousuf et al, 2011). Another study was conducted by Re-Team Corporation and Waste Concern (2015) to estimate the generation of e-waste for Dhaka and its findings are presented in Table 2.6.

Table 2.6: Electronic Item Consumption and E-Wastes for Dhaka (Re-Tem Corporation & Waste Concern, 2015)

Item	**Dhaka Statistical Metropolitan Area (DSMA) (in million pieces)**				**Bangladesh (in million pieces)**
	Consumption in Dhaka (2009)	Consumption in Dhaka (2014)	Consumption in Dhaka (2020)	E-Waste generated in DSMA (2014)	Secondary information on Consumption in Bangladesh (2014)
Mobile Phone	2.88 (considering growth of 20%)	7.16	21.37	1.32	18.00
Computer	0.24 (considering growth of 10%)	0.39	0.68 (considering growth of 10%)	0.10	0.30
Television	0.39 (considering growth of 20%)	0.97	2.90 (considering growth of 20%)	0.07	1.20

ESDO has conducted studies one-waste generation assessment in Bangladesh over a period of time ranging from 2010-2016. Table 2.7 is the compilation of their study findings over that period. It has been found from their study that the generated e waste amount in Bangladesh is around 10 MT upto 2016 whereas the estimated generation of e -waste worldwide is around 50 MT upto 2018. Figures 2.7 and 2.8 show the Bangladesh scenario of generated e-waste.

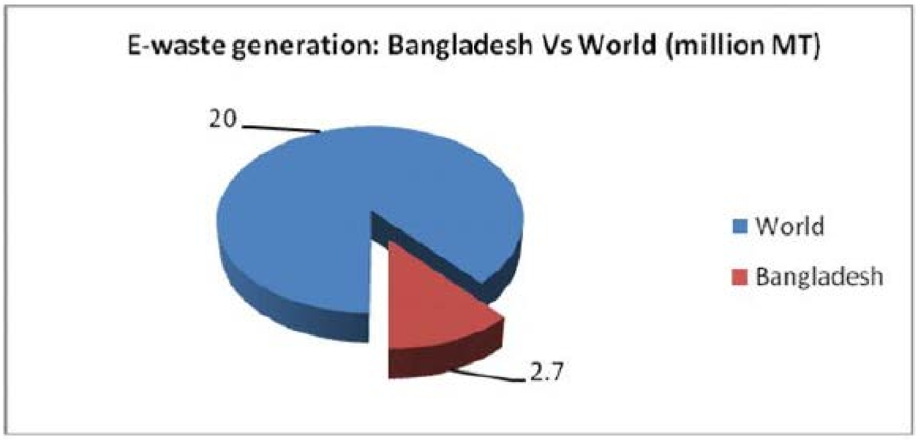


Figure 2.7: E-Waste Generation in Bangladesh Vs World (ESDO, 2010)

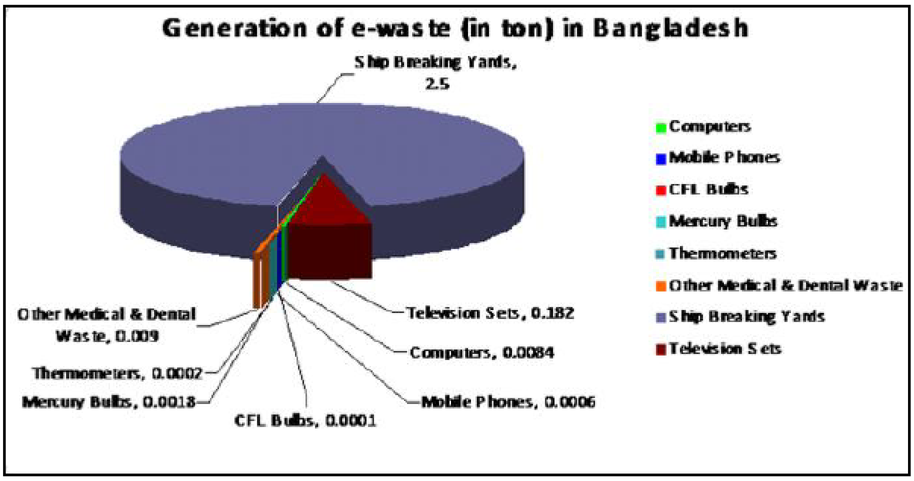


Figure 2.8: E-Waste Generation in Bangladesh (ESDO, 2010)

Table 2.7: Commonly Used Equipment and Yearly Generated Amount of E-Waste (ESDO, 2010, 2014, 2016).

E-Waste	Amount of E Waste Generated (Million Metric Ton)		
	Year 2009- 2010	Year 2011-2012	Year 2013-2014
Total E-Waste	2.71	5.09	9.82 (upto 2016)
E-waste from Ship Breaking Yard	2.5	4.7	8.86
Personal Computers	0.0084	0.0167	0.0307
CFL	0.001	0.002	0.0032
Mobile Phones	0.0006	0.006	0.0211
Television	0.182	0.35	0.86

2.3.2.1 E-Waste from Ship Breaking Industry

Bangladesh consistently places as one of the top 3 ship breaking countries in the world. It scrapped around 270 ships in 2012 (placing second) and 210 ships in 2013(placing third) (Shipbreakingbd.info 2018). Ship breaking scenario of Bangladesh and other countries are showed in Figure 2.9 and Figure 2.10.

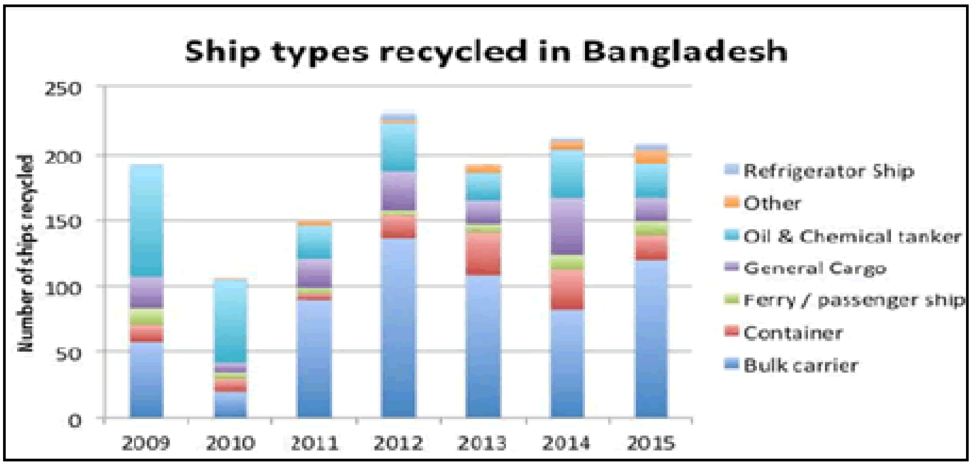


Figure 2.9: Total Number of Ships Recycled in Bangladesh by Type/Category between the Years 2009 to 2015 (Sujauddin et al., 2014)

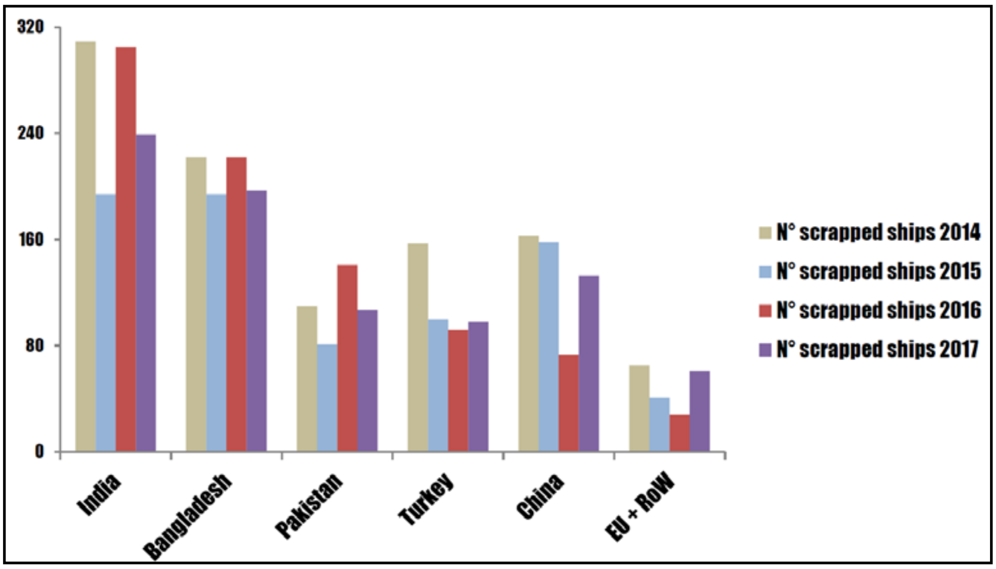


Figure 2.10: Comparison of Number of Ships Scrapped Annually (Shipbreakingplatform.org 2018)

Ship breaking yards account for most of the e-waste generated in Bangladesh. While majority of the scrap produced is sent to steel re-rolling mills, the electronic communication equipment and on-board sensors are salvaged as e-waste and sold in various scrap retail points, such as CDA market, Bhatiary, Coxy Market, Ice Factory Road of Chittagong and so on. But on-board electronics only account for a tiny fraction of the e-waste generated from ship breaking yards (though official statistics are unavailable). According to a survey by the Environment and Social Development Organization (ESDO), huge amount of e-waste is illegally imported from abroad in containers that come aboard these scrap ships. According to Table 2.7, ship breaking yards are the prime source of e-waste in Bangladesh (ESDO, 2016). Mobile phones appear to have very low contribution to annual tonnage.

2.3.2.2 E-Waste from Cell Phone Market

Smart phone penetration in the Bangladeshi market has increased exponentially. According to GSMA (2018), almost half of the population of the country were unique subscribers of telecom services by the end of 2016 (Table 2.8).

Table 2.8: Mobile Market in Bangladesh (GSMA, 2018)

	Unique Subscriber Penetration	**Mobile Internet Penetration**	**Proportion of 3G Connections**	**Proportions of 4G Connections**
Bangladesh	53%	33%	20%	0%
India	48%	35%	18%	1.7%
Southern Asia	50%	34%	21%	1.9%
World	65%	48%	32%	23%

According to Bangladesh Mobile Phone Importers Association (BMPIA), smart phone imports have increased exponentially in the last few years. From Figure 2.11, it is evident that a considerable number of cell phones will become as e-wastes at the end of their life span.

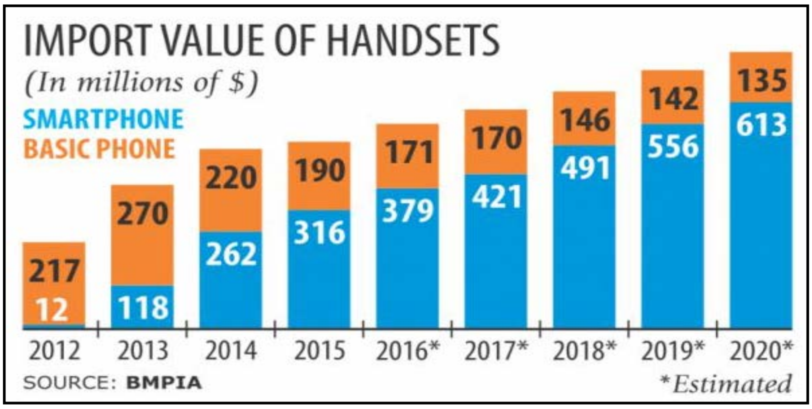


Figure 2.11: Value of Smartphone Imports in Bangladesh (Islam, 2016)

2.4 EFEFCTS OF E-WASTE ON HUMAN HEALTH AND ENVIRONMENT

When e waste is disposed of or recycled without appropriate measures, there are adverse impacts on environment and human health. It has been found that e waste contains more than 1000 substances, many of which are toxic and harmful elements such as lead, cadmium, mercury, beryllium, chromium, etc. (Babu et al, 2007). Other harmful substances of e wastes include arsenic, chloroflouro carbon (CFC), Persistent Organic Pollutants (POP) such as polybrominated diphenyl ethers (PBDE), polychlorinated biphenyl (PCB) etc. Some of the major toxic components found in e-waste are shown in Table 2.9. Handling or re-using of such e wastes without proper care can cause health hazards and environmental pollution. E waste should not be combined with unsorted municipal wastes and dumped into a landfill. The leaching of hazardous, toxic components from this e waste can penetrate the soil causing soil pollution and with the help of rainwater it can contaminate surface and ground water.

Table 2.9: Toxic Constituents of E-Waste

Components	Constituents
Printed Circuit Board (PCB)	Lead and Cadmium
Cathode Ray Tubes (CRTs)	Lead Oxide and Cadmium
Switches and Flat Screen Monitor	Mercury
Computer Batteries	Cadmium, Lithium
Capacitors and Transformers	Polychlorinated Biphenyls
Printed Circuit Board, plastic casing cables	Brominated Flame Retardant (BFR)
Cable insulation/coating	Polyvinyl chloride
Mercury bulb	Mercury
Wires, cables	Copper
Computer Motherboards	Beryllium

There are a number of ways through which e waste goes to the environment and pollute air, water and soil. In developing countries like Bangladesh, about 20-30% of total e waste is recycled and rest 70-80% of e waste goes to the landfill (Yousuf et al., 2011). It has been reported that about 40% of the heavy metals found in landfill comes from e wastes (Montrose, 2011). The landfill leachate containing acids from melting of computer chips causes acidification of soil and thereby releases toxic metals into the soil and water sources. It has been found that lead from the cone glass of cathode ray tubes gets mixed with acid water and is a common occurrence in landfills. There is a chance of mercury leaching when certain electronic devices such as circuit breakers are destroyed. The vaporization of metallic mercury and dimethylene mercury and release of polychlorinated biphenyls (PCB) from condensers are also concern. When brominated flame retardant plastic or cadmium containing plastics are land filled, both polybrominated diphenyl ethers (PBDE) and cadmium may leach into the soil and contaminate groundwater. Incineration and open burning of e waste emits toxic fumes and gases and causes air pollution (Figure 2.12).

Figure 2.12: Burning of Wires in Open Air

Improper and unregulated methods of recycling and recovery also affect the environment. Crude ways of dismantling and desoldering can often lead to release of toxic emissions which pollute the air. The impact is severe during burning of circuit boards in open air to recover copper and other metals. Extraction of metals through acid bath method or through mercury amalgamation also contributes to environmental degradation. The environmental impacts of different e-waste components through various processes are shown in Table 2.10

Table 2.10: Effects of E-Waste on Environment (Pinto, 2008)

E waste Components	Process used	Potential Environmental Hazard
Cathode Ray Tubes (used in TV, computer monitor, video camera, ATM etc)	Breaking and removal of copper yoke and dumping	Lead, Barium and other heavy metal leaching into ground water and release of toxic phosphor
Printed Circuit Board (a thin plate on which chips and other electronic components are placed)	DE soldering and removing computer chips, open burning and use of acid bath to recover other metals after chips are removed	Air emissions as well as discharge into rivers of glass dust, tin, lead, brominated dioxin, beryllium, cadmium
Chips and other gold-plated components	Chemical stripping using nitric and hydrochloric acid and burning of chips	Hydrocarbons, heavy metals, brominated substances discharged directly into river acidifying fish and flora. Tin and lead contamination of surface and groundwater. Air emissions

E waste Components	Process used	Potential Environmental Hazard
		of brominated dioxin and hydrocarbons.
Plastics from printers, monitors etc.	Shredding and low temperature melting	Emissions of brominated dioxin, heavy metals and hydrocarbon
Wires/cables	Open burning and stripping to recover copper	Hydrocarbon, ashes including PAHs release into air, water, soil

The main risks to human health arise from the presence of heavy metals, POPs, flame retardants and other potentially hazardous substances in e wastes. The health hazards of these substances are presented in Table 2.11. There are three main groups of substances that may release during recycling and material recovery: i) original constituents of equipment such as lead, mercury, ii) substances that may be added during recovery process such as Cyanide, acids and iii) substances that may be formed by recycling process such as Dioxins. In developing countries like Bangladesh, e waste collection and recycling sector is largely informal, unregulated and process of recovering materials takes place in small workshops following crude methods. Of most concern is the manual dismantling and recovery of valuable parts from wires, cables, CRTs and Printed Circuit Boards (PCBs). Excessive level of metals (As, Cr, Li, Mb, Ag, Be, Cd, Cu, Ni, Pb, Zn etc.) recovery takes place by acid leaching operations. There exists a risk of accidental release and spillage of hazardous substances such as mercury during breaking of the shell of mercury bulb and switches. CRTs present the risk of implosion due to the vacuum inside the tubes and inhalation hazards due to phosphor coating on the inner side of the glass. Manual disassembling of e wastes to separate metals (mainly Cu and Al) and open burning of cables and wires to recover Cu from plastics increase the risk of formation of dioxin since copper electrical wiring is coated with chlorine containing PVC plastic. The primary hazards of mechanical treatment methods involve size reduction and separation, which can create plastics, metals and silica. The dust may pose an inhalation hazard from polycyclic aromatic hydrocarbons (PAHs) and dermal exposure to the workers. In addition, with lack of access to running water, toxins can be transmitted orally via workers hand while eating. Mixtures of conc. Nitric and hydrochloric acid are used to extract gold and copper from PCBs. Various volatile compounds of nitrogen and chlorine are known to be emitted during this process. The heating of PCBs for desoldering and removal of chips exposes workers to fumes of metals, particularly lead and tin which may pose serious health hazards to the workers.

Table 2.11: Effects of E-Waste on Human Health (Lundgren, 2012)

Chemical	Source in E-Wastes	Health Effects
Antimony	CRTs, printed circuit boards (PCBs) etc.	Very hazardous in ingestion, in event of skin and eye contact, and inhalation. Causes damage to the blood, kidneys, lungs, nervous system, liver and mucous membranes
Arsenic	Used to make transistors	Soluble inorganic arsenic is acutely toxic and intake of inorganic arsenic over a long period can lead to chronic arsenic poisoning. Effects, which can take years to develop, include skin lesions, peripheral neuropathy, gastrointestinal symptoms, diabetes, renal system effects, cardiovascular disease and cancer
Barium	Front panel of CRTs	Short-term exposure causes muscle weakness and damage to heart, liver and spleen. It also produces brain swelling after short exposure
Beryllium	Motherboards of computers	Carcinogenic (causing lung cancer), and inhalation of fumes and dust can cause chronic beryllium disease or beryllicosis and skin diseases such as warts
Cadmium	Chip resistors and semi-conductors	Has toxic, irreversible effects on human health and accumulates in kidney and liver. Has toxic effects on the kidney, the skeletal system and the respiratory system, and is classified as a human carcinogen
CFC	Older freezes and coolers	Found to destroy the ozone layer and is a potent greenhouse gas. Direct exposure can cause unconsciousness, shortness of breath and irregular heartbeat. Can also cause confusion, drowsiness, coughing, sore throat, difficulty in breathing, and eye redness and pain. Direct skin contact with some types of CFCs can cause frostbite or dry skin
Cobalt	Rechargeable batteries and coatings for hard disk drives	Hazardous in case of inhalation and ingestion and is an irritant of the skin. Has carcinogenic effects and is toxic to lungs. Repeated or prolonged exposure can produce target organs damage
Copper	Used as a conductor	Very hazardous in case of ingestion, in contact with the eyes and when inhaled. An irritant of the skin and toxic to lungs and mucous membranes. Repeated or prolonged exposure can produce target organs damage
Dioxin	Created when electronics are burnt in open air	Highly toxic and can cause chloracne, reproductive and developmental problems, damage the immune system, interfere with hormones and cause cancer
Gallium	Integrated circuits, optical electronics, etc.	Hazardous in case of skin (may produce burns) and eye contact, ingestion and inhalation. Severe over-exposure can result in death. Toxic to lungs and mucous membranes. Repeated or prolonged exposure can produce target organs damage

Chemical	Source in E-Wastes	Health Effects
Hexavalent Chromium	Used as corrosion protection of untreated and galvanized steel plates and hardener for steel housings	Damages kidneys, the liver and DNA. Asthmatic bronchitis has been linked to this substance. Causes irritation of the respiratory system (asthma) and skin, liver and kidney damage, increased or reduced blood leukocytes, eosinophilia, eye injury, and is a known carcinogen (lung cancer)
Indium	LCD screens	Can be absorbed into the body by inhalation or ingestion. Is irritating to the eyes and respiratory tract and may have long-term effects on the kidneys. Environmental effects have not been investigated and information on its effects on human health is lacking; therefore, utmost care must be taken
Lead	Solder of printed circuit boards, glass panels and gaskets in computer monitors	Causes damage to central and peripheral nervous systems, blood systems and kidneys, and affects the brain development of children. A cumulative toxicant that affects multiple body systems, including the neurological, hematological, gastrointestinal, cardiovascular and renal systems
Lithium	Rechargeable batteries	Extremely hazardous in case of ingestion as it passes through the placenta. It is hazardous and an irritant of the skin and eye, and when inhaled. Lithium can be excreted in maternal milk
Mercury	Relays, switches and printed circuit boards	Elemental and methyl-mercury are toxic to the central and peripheral nervous system. Inhalation of mercury vapor can produce harmful effects on the nervous, digestive and immune systems, lungs and kidneys, and may be fatal. The inorganic salts of mercury are corrosive to the skin, eyes and gastrointestinal tract, and may induce kidney toxicity if ingested
Nickel	Rechargeable Batteries	Slightly hazardous in case of skin contact, ingestion and inhalation. May be toxic to kidneys, lungs, liver and upper respiratory tract. Also has carcinogenic effects
Perfluoro octane sulfonate PFOS/F)	Photo resistant and antireflecting coating	Persistent, bio-accumulative and toxic to mammalian species; linked to increases in the incidence of bladder cancer
Pythalates	Used to soften plastic	Disrupts the endocrine system, reproduction, fertility and birth, and has developmental effects. Also has organ system toxicity and is linked to liver cancer and effects on the brain, nervous system and immune system
Polybrominated diphenyl ethers (PBDEs) used in brominated flame	Plastic housing of electronic equipment and circuit boards to reduce flammability	PBDEs are of concern because of their high lipophilicity and high resistance to the degradation processes. Hepatotoxicity, embryotoxicity and thyroid effects seem to be characteristic endpoints in animal toxicity, and behavioral effects have

Chemical	Source in E-Wastes	Health Effects
retardants (BFRs)		been demonstrated. BFRs in general have been shown to disrupt endocrine system functions and may have an effect on the levels of thyroid stimulating hormone and cause genotoxic damage, causing high cancer risk.
Polychlorinated biphenyls (PCBs)	Insulating material in older electronic products	Linked to reproductive failure and suppression of the immune system
Polyvinyl Chloride (PVC)	Cabling and computer housing plastics contain PVC for its fire-retardant properties	Produces dioxins when burnt; causes reproductive and developmental problems, immune system damage and interferes with regulatory hormones
Silver	Wiring Circuit Boards etc.	Very hazardous in case of eye contact, ingestion and inhalation. Severe over-exposure can result in death. Repeated exposure may produce general deterioration of health by an accumulation in one or many human organs
Thallium	Batteries, semi-conductors etc.	Very hazardous in case of ingestion and inhalation. Also hazardous in case of skin and eye contact. May be toxic to kidneys, the nervous system, liver and heart, and may cause birth defects. Severe over-exposure can result in death
Tin	Lead-free solder	Causes irritation in case of skin and eye contact, ingestion and inhalation. Can cause gastrointestinal tract disturbances, which may be from irritant or astringent action on the stomach
Zinc (Chromates)	Plating material.	Contact with eyes can cause irritation; powdered zinc is highly flammable; if inhaled, causes a cough, and if ingested, abdominal pain, diarrhea and vomiting is common

In developing countries, workers, mostly women and children are engaged in e waste recycling jobs and are the most vulnerable ones through inhalation, dust ingestion and dermal exposure (Figures 2.13 and 2.14). The most evident health issues are related to occupational and direct local exposure. In addition to direct occupational exposure, people can also come into contact with e waste materials and associated pollutants through contact with contaminated soil, air, water and through food sources. The children of e waste recycling workers also face take home contamination from their parent's clothes, skin and direct high-level exposure if recycling, recovery is taking place in their homes. Children at recycling sites are reported to be suffering from medical problems such as breathing ailments, skin infections and stomach diseases. Research findings reveled that in Guiyu, China, about 80% of children suffered from respiratory diseases (Sepulveda et al., 2010) and showed evidence of high concentration of lead in blood and increase cases of leukemia (Tsydenova & Bengtsson, 2011).According to ESDO (2010), approximately fifty thousand children are involved in informal collection and recycling of e wastes in Bangladesh and every year more than 15% of child workers die as a result of e waste recycling and 83% are exposed by toxic substances and become sick and are forced to live with long term illness (Karim et al., 2014). Another study revealed alarming concentrations of PBDEs in human hair from workers at an e waste recycling plant in Eastern China, ranging from 22.8 – 1020 ng/g (three times higher than control area) and PCDD/F ranging from 126-5820 ng/g (18 times higher than control area) (Cheng et al., 2011).

Figure 2.13: Woman Engaged in E-Waste Separation

Figure 2.14: Manual Recycling of E-Waste Components by Child Labour

The degree of hazard posed to workers and environment varies greatly depending on the individuals and the nature of operations. It is evident from several studies that workers suffer high incidences of tuberculosis, blood diseases, anomalies in the immune system, kidney and respiratory problems, lung cancer, damage to the nervous system etc. (Frazzoli et al., 2010; Sepulveda et al, 2010). However, long- term health effect is yet to be conducted.

Long range transport of pollutants has also been observed, which suggests a risk of secondary exposure in remote areas. Atmospheric pollution due to burning and dismantling activities seems to be the main cause of occupational and secondary exposure (Sepulveda et al., 2010). Informal sector e waste activities are also a crucial source of environment-to -food-chain contamination as contamination may accumulate in agricultural lands and be available for uptake by grazing livestock. In addition, most chemicals of concern have a slow metabolic rate in animals and bioaccumulate in tissues and be excreted in edible products such as eggs and milk. (Frazzoli,et al., 2010) (Figure 2.15).

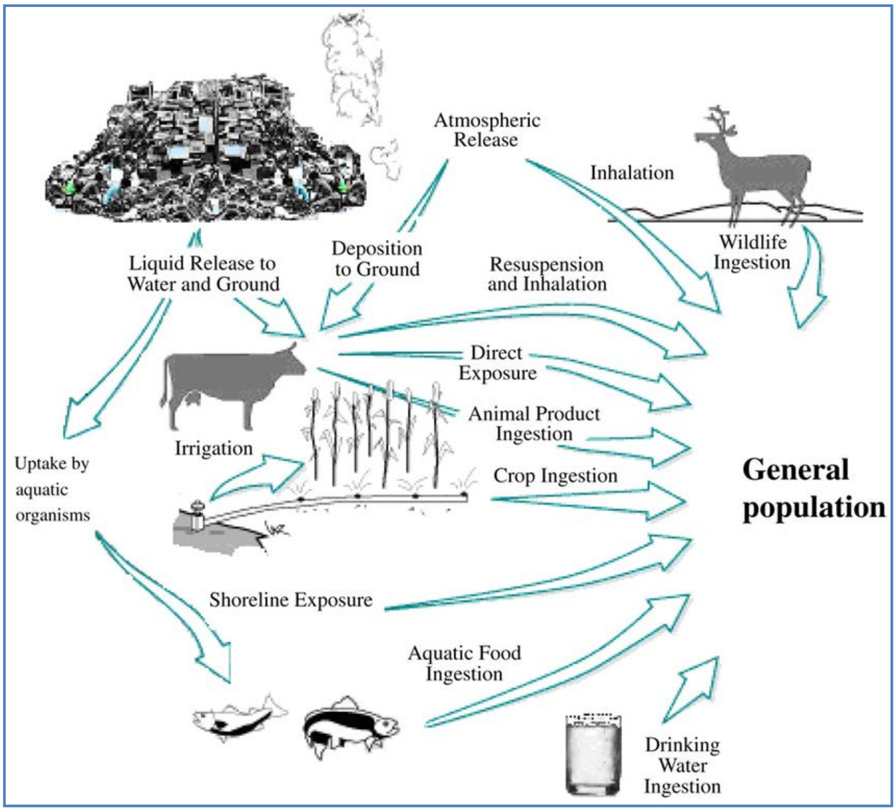


Figure 2.15: Exposure Routes and Fate of E-waste in Environment and Food Chain (Frazzoli et al., 2010)

E-Waste therefore constitutes a significant environmental and health problem, with implications far broader than occupational exposure and involving vulnerable groups and generations to come.

2.5 E-WASTE MANAGEMENT SYSTEM

Like municipal solid waste management system (MSWM), e-waste management system should have functional elements such as handling, collection, storage, separation, processing, treatment, recovery, recycling and disposal (Figure 2.16). More importantly, e-waste needs to be properly handled, as many of these items contain toxic and hazardous elements and its effects on environment is significant and occupational health risk is severe. To have an effective management system of e -waste, it is necessary to understand the pathway of e-waste starting from its generation to its ultimate fate (Figure 2.17). The processes of recovery and recycling involved in e waste management system are very important part. Recycling involves the dismantling of the item, and the removal of many different e-waste parts, some of which could contain dangerous substances that should not just end up in a landfill. Recovery of useable and precious metal from e waste also needs to follow proper and controlled procedure.

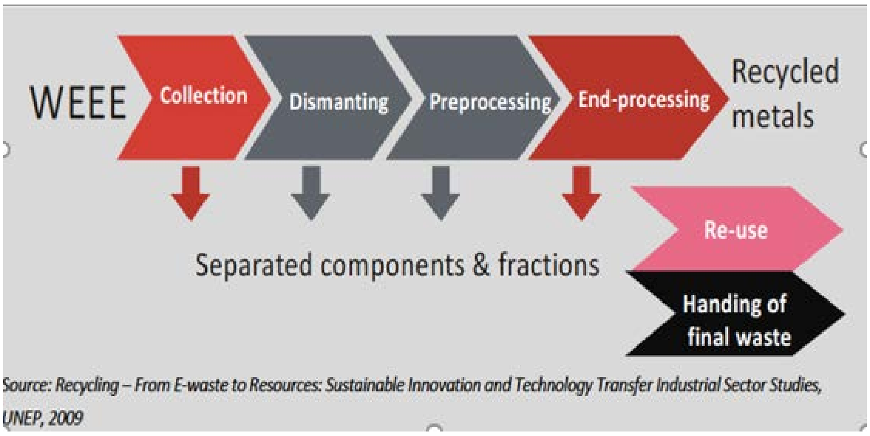


Figure 2.16: Elements of E-Waste Management System (Schluep et al., 2009)

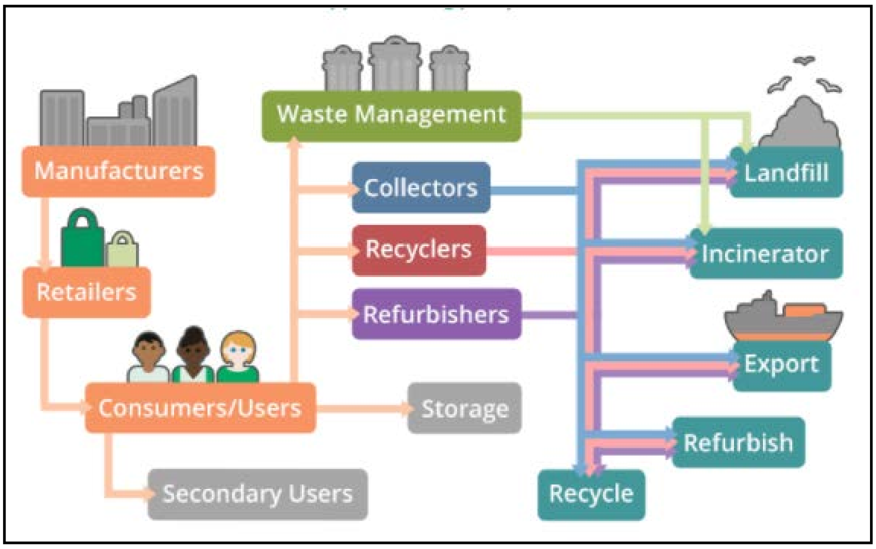


Figure 2.17: E-Waste Recycling Process Flow (Schluep et al., 2009)

2.5.1 General Framework of E-Waste Management System

First world countries are pioneers in developing awareness of the e-waste situation and formulating appropriate strategies and legislation to mitigate this problem. In fact, Switzerland is the first country to introduce a comprehensive e-waste management system which paved the way for policymaking in other countries in the developed world (Sinha-Khetriwal et al., 2005). E-waste management systems currently prevalent in the developed world are mostly similar. Thus, a framework for a standard e-waste management system can be developed from a survey of existing practices.

Collection System and Inventory- in developing countries, e-waste is collected by agents operating in an informal economy, like hawkers. As it is an informal economy, there is no record of e-waste flow from households to disposal sites through vendors. There is no supervision of environmental standards and worker health issues either. In developed countries, e-waste is collected by producers or a consortium of producers. There is meticulous bookkeeping of the amount of e-waste collected, so there is adequate data to assess the criticality of the e-waste situation and the required immediacy of action. This data is absent in developing countries, thus exacerbating their vulnerability.

Legal Framework **–** developed countries have formulated and implemented detailed legal policies that define categories of e-waste, delineate responsibilities of producers and e-waste processors in collecting and processing e-waste, enunciates the environmental standards that must be upheld throughout the management system and provides punitive measures for actors who defy the system. Developing countries often imitate these legal frameworks but fail to implement them in absence of the required infrastructure (Pariatamby and Victor, 2013). In developing countries, the vast informal economy surrounding e-waste disposal means that the socioeconomic context is fundamentally different from developed countries. If foreign legal frameworks are supplanted without integrating the extant actors in the informal economy, livelihoods will be destroyed and may create considerable social unrest.

Financing of the system **–** for the system to be feasible, it must generate enough revenue to pay for its own expense. The *Extended Producer Responsibility* (EPR) initiative in developed countries have been universally proved to be effective in this end. It charges the producer with financial and physical responsibility of e-waste recycling under regulatory supervision. There are many possible approaches to EPR as can be seen in Table 2.12. Policy instruments used in EPR are detailed in Table 2.13. Funds are collected from consumers as Advance Recycling Fees that is incorporated in the retail price of consumer goods. Producers also contribute to the fund by paying disposal fees to e-waste processing centers while handing over their collected e-waste. In this way, revenues surpass the operating cost of the system and make it agreeable to all stakeholders (Khetriwal et al., 2009).

Table 2.12. Different Approaches to EPR (Widmer et al., 2005)

Type of EPR approach	Example
Product take-back programs	• Mandatory take-back • Voluntary or negotiated take-back programs
Regulatory approaches	• Minimum product standards • Prohibition of certain hazardous materials • Disposal bans • Mandated recycling
Voluntary industry practices	• Voluntary codes of products • Public/private ownership • Leasing and “servicing” • Labelling
Economic Instruments	• Deposit-refund schemes • Advance Recycling Fees(ARF) • Disposal Fees • Material taxes/subsidies

Table 2.13. Policy Instruments Used in EPR Implementation (Van Rossem et al., 2006)

Administrative instruments	Collection and/or take-back of discarded products, reuse and recycling targets, setting emission limits, recovery obligation, product standards, technical standards
Economic instruments	Material/Product taxes, subsidies, advance disposal fee systems, deposit-refund systems, upstream combined tax/subsidies
Informative instruments	Environmental reports, environmental labeling, information provision to recyclers about the structure and substances used in products, consultation with authorities about collection network

***Waste disposal technology* –** developed countries possess the advanced technology to reclaim precious metals, polymers and other raw materials from e-waste in an environment friendly manner. This value reclamation eases the pressure on earth’s dwindling ores of precious metals, as well as reducing the need for mining activities which are highly polluting. So far, developing countries are only dismantling e-waste into their constituent components and exporting them back to processing facilities in developing countries. Acquiring the appropriate waste disposal technology will complete the e-waste management system in developing countries while adding plenty of jobs to the economy.

Developing countries and developed countries differ in e-waste management system in one crucial aspect – whereas almost the entirety of the generated e-waste is systematically handled in developed countries, most of the recycling and recovery in developing countries is carried out by the informal sector following crude and improper method. Moreover, efficient and systematic collection system is absent in developing countries. As a result, relevant statistics are hardly available and there is no way to assess and ascertain safety standards in this industry. In the following sections, the e-waste management scenarios of two neighboring developing countries (Bangladesh and India) are described along with a developed country (France).

2.5.2 E-Waste Management in Bangladesh

In Bangladesh, there exists no systematic arrangement for e-waste management. The collection, dismantling, recovery and recycling of e waste is mainly done by informal sectors following manual and crude procedure (Figure 2.18). Since there is no law or rule regarding e waste management and due to the unawareness of consumer, most of the e -waste remain uncollected and they end up in the landfill site along with other solid wastes. According to a study conducted by ESDO (2016) showed that for fully damaged electronic devices, 50% of waste is disposed of and for partially damaged equipment, about 90% get repaired (Figure 2.19) in Bangladesh.

Figure 2.18: Workers Manually Dismantling Scrap Electronics (ESDO, 2010)

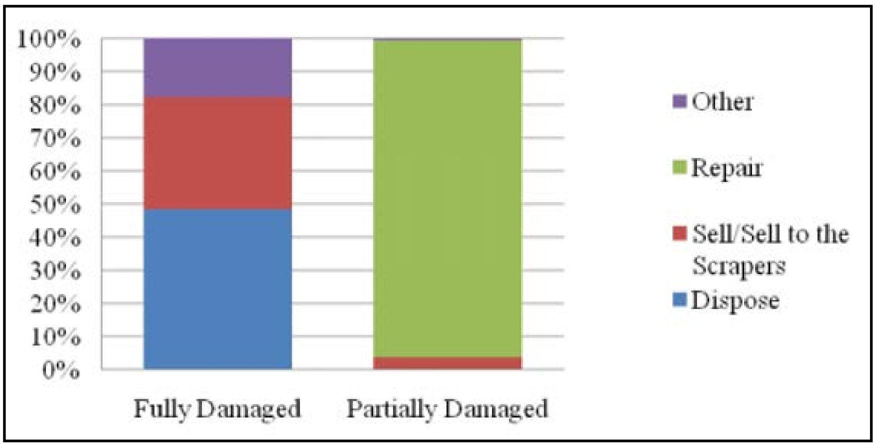


Figure 2.19: Pattern of E-Waste Management Practice (ESDO, 2016)

The e-waste management system which exists in Bangladesh is presented in Figure 2.20. E-waste Importers also source the materials from abroad at a cheap price and sell them in the local market. Refurbishers use working components from these waste electronics to restore out-of-service local e-waste to service conditions. Products which cannot be refurbished are dismantled, scavenged for value metals and dumped in landfills (Lepawsky, 2011). The E-waste industry of Bangladesh is concentrated in a few locations in Dhaka: dismantling activities take place in Elephant Road, Gulistan, Kotwali and Motijheel. Metals, plastics and glass are moved to Lalbagh and Kotwali for reconfiguration into household goods like plastic containers and cutlery. Kotwali is the recipient of precious metals such as gold, which are sold wholesale to the jewelry sector for production. Open burning, dumping of e-waste in landfills and manual desoldering of circuit boards are common techniques used by informal recyclers to extract value metals such as copper from the circuit boards (Karim et al., 2014). Burning is highly inappropriate as it releases lots of toxic heavy metals and unburnable, insoluble plastics into the environment (Berkhout, 2004).

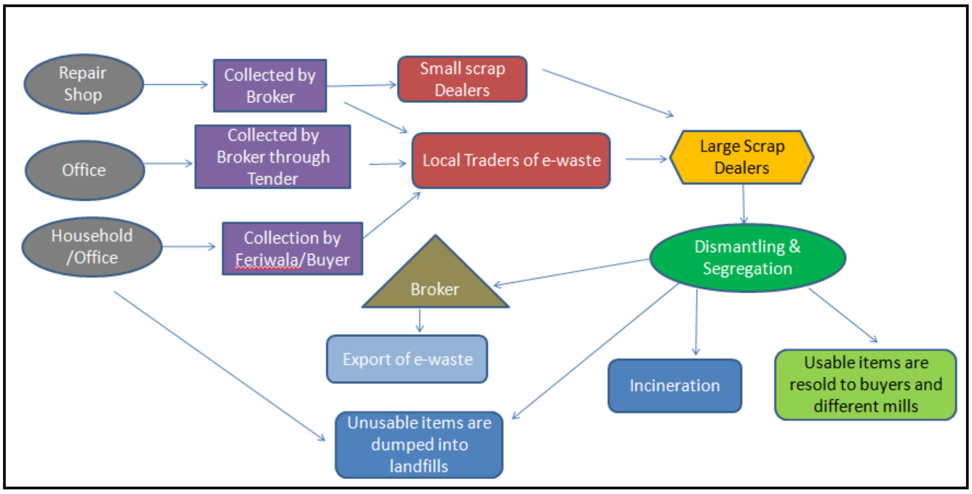


Figure 2.20: E-Waste Flow Diagram in Bangladesh

The value addition occurs to the e-waste stream by means of repairing, remanufacturing and dismantling. Hence, it could be said that e-waste in Bangladesh is not necessarily treated as "waste" but as products with enough remaining utility to constitute an entire industry. Formalization of this highly potential industry will ensure worker safety, create more jobs, add revenue to the state coffers and contribute to sustainable development practices in the country. The success of any e-waste recycling initiative depends on the awareness of the consumers. Consumers are an integral part of the recycling process, either in paying an Advanced Recycling Fee at the time of purchase of electronic devices or disposing the e-waste at designated sites. Ahmed (2011) comments that while the awareness level about e-waste situation is very low in Dhaka households, there is a surprisingly high willingness to pay for e-waste disposal arrangements. A survey was conducted on 185 households across 90 wards in Dhaka.

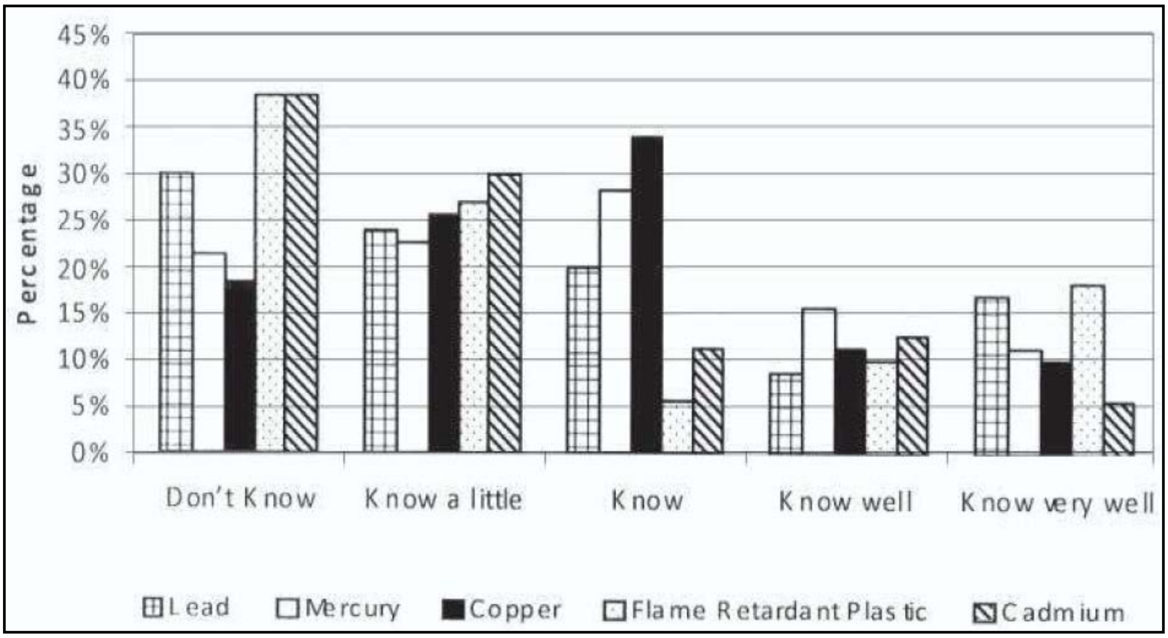


Figure 2.21: Familiarity with Heavy Metals Found in E-waste (Ahmed, 2011)

Figure 2.21 shows that very few city-dwellers know about the harms of heavy metals present in their electronic appliances. However, in the same study the author had also found that people were willing to contribute an average of BDT 1017 to a hypothetical e-waste management fund, which would be a one- time payment. This response can be used as a benchmark for formulating environmental conservation tax and consumer reasonability policies.

2.5.3 E-Waste Management in Developed Countries

Currently developed countries are giving top priorities in managing the e-wastes realising its fast generation and threat to environment and human health. As a result, they have been developing policies and systems to confront the problem, some of which are becoming ever-more sophisticated.

European countries, in particular, have developed e-waste systems that rely heavily on the principle of Extended Producer Responsibility (EPR). EPR stipulates that the manufacturer of an electrical or electronic device bears responsibility for that product beyond the initial sale. This is a core principle of the European Union's Waste Electronic and Electrical Equipment (WEEE) Directive, which outlines the producer's responsibility to manage the collection and recycling of these products. Crucially, this principle requires the producer to assume the cost of the recycling. Thus, producers of electrical and electronic devices in Europe have a financial interest in the life cycle of these products and thereby they are emphasizing on the recycle and recovery options. The e-waste system being developed in Europe, in particular, involves not only national governments, producers and recyclers, but also consumers, retailers and municipalities.

For example, in France, manufacturers can choose to dispose the end-of-life products by themselves or financially contribute to eco-organizations to do that on their behalf. The latter is the more popular option. There are 3 such eco-organizations – *Ecosystems*, *Eco-logic* and *ERP* (European Recycling Platform).

There are two different approaches to collecting these wastes: the first has individuals deliver e-waste to collection points inside cities (Figure 2.22). There are more than 22,900 collection points in France, which are main players in collection process. Eco-Logic, Eco-Systems andERP manage these points and deliver waste to recovery centers. The second approach involves producers or individuals using out-of-town recovery centers. There are more than 4500 centers in France for the second approach (Agence de l'Environnement et de la Maîtrise de l'Énergie, 2014).

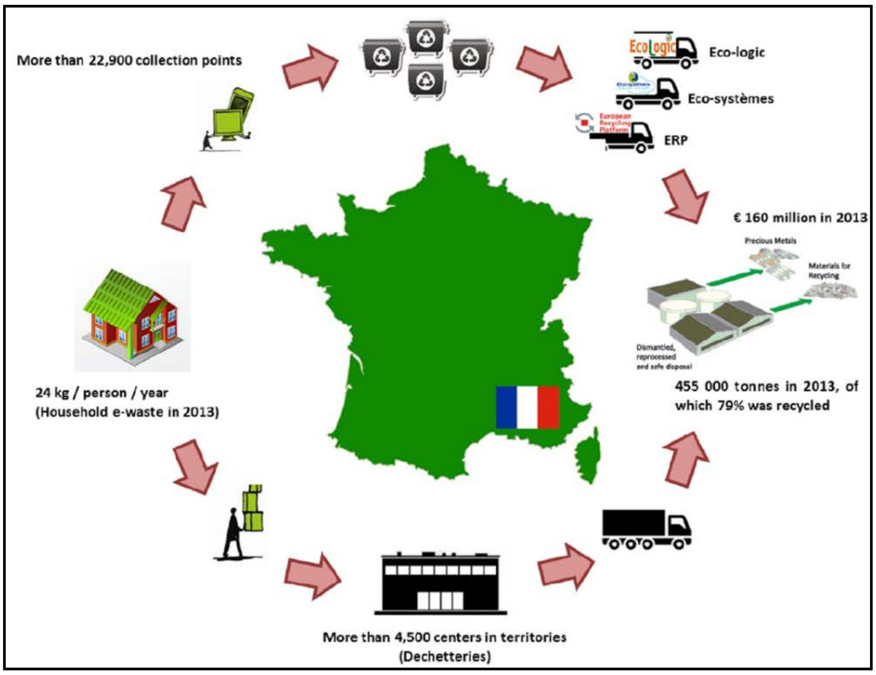


Figure 2.22: E-Waste Management in France (Vadoudi, 2015)

The material and financial flow are illustrated in Figure 2.23.

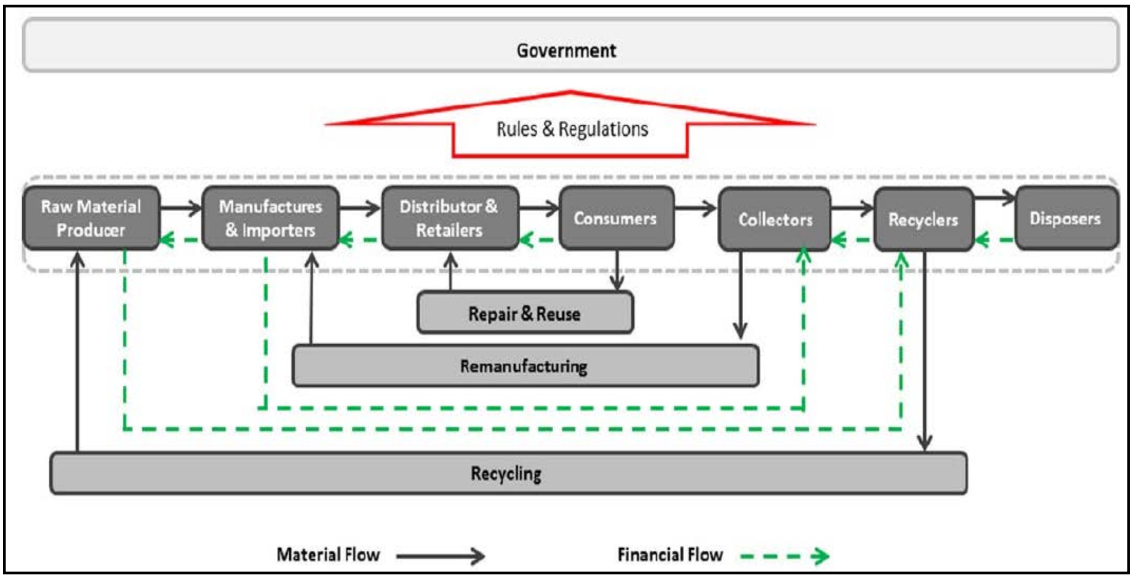


Figure 2.23: Material and Financial Flow of E-waste Management in France (Vadoudi, 2015)

Required finance for day-to-day functioning of the system (for collection, transport and recycling/disposal) is generated from different taxes, which have been applied since November 2006 (CNRS, 2015). Producers pay a fee for each product they supply onto the French market to their nominated E-waste. The fees vary according to the products and E-waste. A standard percentage increase and decrease is applied to the product fee for six specific products based on specific design for dismantling, recovery and reuse criteria. Developing these criteria were based on three fundamental principles: life cycle and durability criteria, hazardous material content and recycled content.The smooth functioning of the system is ensured by DREAL (directions régionales de l'Environnement, de l'aménagement et du logement) (Ministry of Sustainable Development, 2015), a unified regional level of the Ministry of Sustainable Development that was established in December 2007. These government agencies like DREAL, which handle environmental affairs, are typically given the additional responsibilities associated with supervising system operations. These responsibilities might include collection fees, reimbursing collectors and processors, setting and enforcing treatment standards, enforcing sales bans on original equipment manufacturers who do not comply with take-back system laws and approving processors and collectors to take part in the system. Government entities may be tasked with supervising a single take-back system for an entire region or multiple systems within a region.

Australia's e-waste management is guided by the National Waste plan and has at its core the Product Stewardship Act. Like the EU's WEEE directive, producers and importers of electrical and electronic devices in Australia bear a financial responsibility for the life cycle of their products. But coverage under Australia's e-waste system, outside of voluntary schemes, is limited to personal computers, computer accessories and televisions, whereas the EU directive applies to a much broader range of electrical and electronic equipment.

Country like Japan adopts a different approach, for example, places the majority of the cost on the consumer, who pays a fee when recycling.Some countries, including Japan and Finland, are also making a special effort to encourage the collection and recycling of smaller devices.

2.6 LEGISLATION AND POLICIES REGARDING E-WASTE MANAGEMENT IN BANGLADESH

According to the Constitution of Bangladesh Article 18A, "the State shall endeavor to protect and improve the environment and to preserve and safeguard the natural resources, biodiversity, wetlands, forests and wild lives for the present and future citizens". With this goal in view, Bangladesh formulated its National Environmental Policy in 1992, which highlighted the regulation of all activities that pollute and destroy the environment. Bangladesh Environment Conservation Act, 1995 (revised in 2012) is currently the main act governing environmental protection in Bangladesh. The major objectives of the act are to preserve the environment through improving environmental standards and controlling and mitigating pollution. Subsequently Environmental Conservation Rule, ECR 1997 sets standards for air, water, noise levels as well as discharges from industries. ECR, 1997 has also classified industries and projects into different categories depending upon their pollution load and likely impact on environment and guidelines for obtaining clearance certificate from the Dept. of Environment (DoE).

There is no comprehensive e-waste policy, although it is briefly mentioned in the country's ICT policy. However, DoE has prepared a draft rule on e-waste management in 2017 to deal with the rising volume of e- waste in Bangladesh. This draft e waste management rule, 2017 has divided e waste into four categories: household appliances, IT and Telecommunication equipment, medical equipment, and monitoring and control equipment. It also addressees the responsibilities for electronic equipment manufacturers/assemblers, e-waste collectors, hoarders, dismantlers, buyers and recyclers in this rule. This draft rule also contains threshold limit for use of some hazardous substances. DoE has also prepared a guideline for e-waste management (DoE, 2016, 2nd Draft). In this guideline, DoE has suggested to adopt the EPR (Extended Producer Responsibility) policy for e-waste management. It has also encouraged the reduce and recycle principles in its management. This e-waste management guidelines contains a list of electrical and electronic equipment which will be included in EPR scheme on a priority basis. The guidelines also contain the principles and implementation process of EPR.

Although no dedicated rules or acts for e- waste management yet, there exists a number of supporting acts, rules, guidelines, strategies and protocol and conventions which can be applicable in e-waste management (Table 2.14).

Table 2.14: Supporting Act, Rules, Strategy and Guidelines for E-Waste management

Legal Instruments	Key Features encompassing e waste management
National 3R Strategy, 2011	The strategy clarifies concepts of reduce, reuse and recycling. It facilitates four types of wastes: solid waste, bio-medical waste, industrial waste and agricultural waste. It does not address e waste as a separate category of waste. However, recycling of e waste is required to be regulated due to presence of hazardous elements in the components of electronic and electrical equipment.
Draft Solid Waste Management Rule,	This draft rule covers the separation, reuse, recycle, processing and disposal process of mainly biodegradable and non-

Legal Instruments	Key Features encompassing e waste management
2017	biodegradable solid waste. Schedule 2, Section 6 of this rule presents a list of domestic hazardous waste which include some items of e waste such as batteries from mobile and button cells, light bulbs, thermometers and mercury containing products etc.
Medical Waste Management Rule, 2008	This rule describes important definition, formation of authority and responsibility, responsibility of registered vendors, segregation, packaging, transportation, and hoarding, elimination and purification, classification of waste for medical waste management. This rule addresses waste management issues mainly in the context of medical wastes.
Lead Acid Battery Recycling and Management Rules, 2006	The rules describe improved collection and recycling of lead acid battery.
The Ship Breaking and Recycling Rules, 2011	This rule describes the process hazardous waste safe management. It includes wastes which is by nature physically reactive, toxic, flammable, explosive and corrosive or other waste properties that can damage health and environment.
National Information and Communication Technology Policy, 2015	The objective of National ICT describes in Section D9 that steps will be taken for the reduction of risks of climate change. By the innovation of environment friendly green technology initiatives will also be taken for safe e-waste management, climate and disaster management. In addition, Section E clearly mentions about safe management of electronic waste. Action plan of this policy includes that industry ministry will establish a plant for reuse of extract metal from refurbish PC and other ICT gadgets (ictd.gov.bd)
Import Policy Order, 2015-2018	The Kha part of this policy describes list of import of prohibited goods. Paragraph no. 5 defines prohibition of imported goods like recondition office equipment, photocopier, type writer machine, telex, phone, fax, old computer and electronic accessories. It means that Bangladesh has banned import of all sorts of e-waste in the Import Policy Order (mincom.gov.bd).
Export Policy Order, 2015-2018	This policy has influenced ICT sector by providing various facilities to the citizen. No restriction has imposed to export refurbished goods including e -devices (mincom.gov.bd)

In 1993, Bangladesh became a signatory of Basel Convention which prohibits trans-boundary movement of hazardous wastes. So, it is implied that Bangladesh is committed for taking measures on e -waste management within its boundary. In seventh five-year plan (2016-2020) of Bangladesh, it is recommended to prepare a guideline of e wastes on a baseline survey. In addition to that, the plan proposes some activities of e waste management. Taking cognizance of the nature and scale of e waste problem of the country, the plan suggests several programs: i) initiating assessment/studies to understand the nature and magnitude of e waste nationwide and developing an action plan ii) undertaking measures to implement the action plan iii) establish efficient collection system for selected electronic wastes. In line with the Draft E-Waste Management Rule, 2017, the sixth five -year plan prominently sheds light on e-waste issues in Bangladesh. It is the high time now to promulgate the Draft E-Waste Management Rule, 2017 by passing it as a law and face the challenges of e- wastes and protect the environment and human health.

2.7 VALUE METAL RECOVERY FROM ELECTRONIC WASTE

2.7.1 Electronic waste as a secondary source of metals

In addition to all the hazards originating from WEEE, manufacturing of mobile phones and personal computers consumes considerable fractions of the gold (Au), silver (Ag) and palladium (Pd) mined annually worldwide (Hadi et al., 2015). The electronics industry is the third largest consumer of gold, accounting for 12% of the total gold demand (about 282 tons) in 2014 (Schipper and Haan, 2015). Worldwide, more than one million people in 26 countries across Africa, Asia and South America work in gold mining, mostly in unregistered substandard conditions (Mccann and Wittmann, 2015), driven by the demand of this precious metal for electronics.

An illustrative explanation of the role of landfill mining, recycling and urban mining is given in Figure 2.24. The reintegration of wastes and by-products back in the economy strongly relies on the concept of waste as a secondary raw material (Jones et al., 2013). In urban mining of end-of-life (EOL) devices, WEEE is a primary target owing to its high content of valuable critical metals. In addition to being a hazardous waste, WEEE is an important secondary source of metals in the transition to a circular economy.

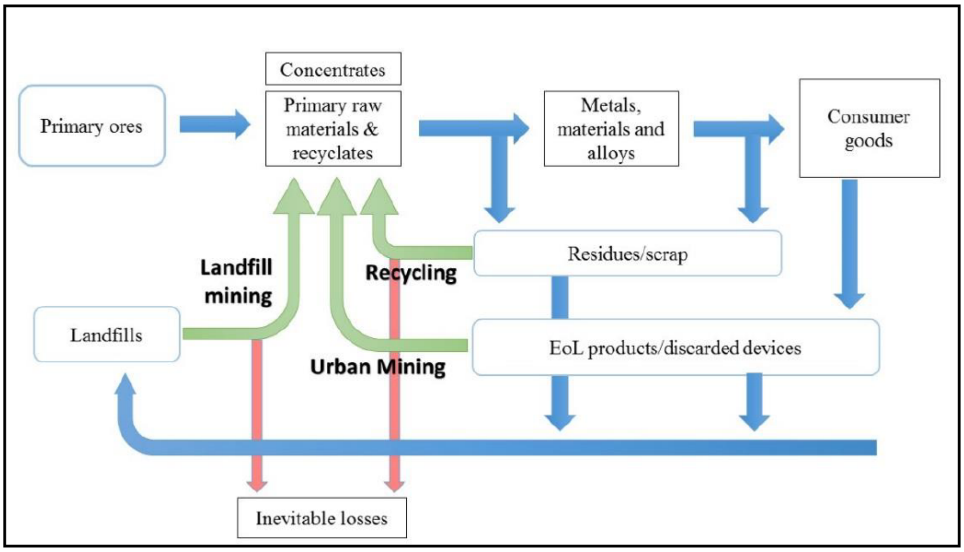


Figure 2.24: Loop of Material Flow in a Circular Economy (Jones et al., 2013)

The complexity of WEEE increased with the development of technology as the production of electronic devices relies on a great number of elements. Modern devices consist of up to 60 elements in various mixtures of metals (Bloodworth, 2014). From the recyclers point of view, highly complex alloys pose a challenge to develop efficient metal recovery technologies from WEEE.

2.7.2 Energy and Resource Conservation

Recycling of e-waste for metal recovery is also important from the perspective of saving energy. The U.S Environmental Protection Agency (Office of Solid Waste, 2008) has identified seven main benefits for using recycled Fe and steel over their virgin materials. One of the major benefits is a significant energy saving using recycled materials compared to virgin materials. The energy savings for a number of common metals and materials are summarized in Table 2.15.

Table 2.15 Recycled Materials Energy Savings Over Extraction from Ores (ISRI, 2003)

Materials	Energy Efficiency (%)
Aluminum	95
Copper	85
Iron and Steel	74
Lead	65
Zinc	60
Paper	64
Plastics	>80

The amount of gold recovered from one ton of e-waste from personal computers is more than that recovered from 17 ton of gold ore. The processes for recovering Precious Metals from electronic scrap, in limited cases are easier than their primary ores (Rankin, 2011). If Precious Metals and Scarce Elements are unrecovered, it will be a significant loss of precious resource.

2.7.3 Economic Value of Targeted Precious Metals

The recovery of precious and base metals is important for e-waste management, recycling, sustainability and resource conservation. The value distribution of PMs in PCBs and calculators is more than 80%.). It is worth noting that sustainable resource management demands the isolation of hazardous metals from e-waste and also maximizes the recovery of PMs. The loss of PMs during the recycling chain will adversely affect the process economy. The extraction of PMs (Au, Ag and Pd) and BMs (Cu, Pb and Zn) from e-waste is a major economic drive due to their associated value, as summarized in Table 2.16.

Table 2.16 Weight vs. Value Distribution in WEEE (Hagelüken, 2006).

Weights%	Fe (wt%)	Al (wt%)	Cu (wt%)	Plastics (wt%)	Ag (ppm)	Au (ppm)	Pd (ppm)
TV-board	28%	10%	10%	28%	280	20	10
PCBs	7%	5%	20%	23%	1000	250	110
Mobile phone	5%	1%	13%	56%	1380	350	210
Portable audio	23%	1%	21%	47%	150	10	4
DVD-player	62%	2%	5%	24%	115	15	4
Calculator	4%	5%	3%	61%	260	50	5
Value-share	**Fe**	**Al**	**Cu**	**Sum PMs**	**Ag**	**Au**	**Pd**
TV-board	4%	11%	42%	43%	8%	27%	8%
PCBs	0%	1%	14%	85%	5%	65%	15%
Mobile phone	0%	0%	7%	93%	5%	67%	21%
Portable audio	3%	1%	77%	19%	4%	13%	2%
DVD-player	13%	4%	36%	47%	5%	37%	5%
Calculator	0%	5%	11%	84%	7%	73%	4%

2.7.4 Metal recovery from Printed Circuit Boards

Most of the electronic equipment are enabled with printed circuit boards as the main component. As a result, the amount of wastes of electric and electronic equipment (WEEE) containing 3% of printed circuit boards are dramatically increasing. The typical composition of PCB is non-metals (plastics, thermosets, glass fibre, ceramics) >70%, copper ~16%, solder ~4%, iron, ferrite ~3%, nickel ~2%, silver 0.05%, gold 0.03%, palladium 0.01%, others (bismuth, antimony, tantalum, etc.) <0.01%.Significant quantities of nonmetallic materials in PCBs (up to 70 wt.%) present an especially difficult challenge for recycling. The nonmetallic materials of PCBs mainly consist of thermosetting plastics (TS), thermoplastics (TP), glass fibers and ceramic fractions. Thermosets cannot be remelted or reformed because of their cross-linked polymeric structure. Incineration is not the best method for treating nonmetallic materials because of the presence of inorganic fillers such as glass fiber, which significantly reduces the fuel efficiency. Disposal in landfill is the main method for treating non-metallic materials of PCBs, but it may cause secondary pollution and resource-wasting. Since the metallic elements are covered with or encapsulated by various plastic or ceramic materials on printed circuit boards, a mechanical pre-treatment process allowing theirliberation and separation is first needed in order to facilitate their efficient extraction with acid or alkali by hydrometallurgical methods. Electronic scrap from printed circuit board can be processed by mechanical methods like stamp, hammer or cutting mill. The value of metals contained in PCB scrap is economic incentives for the recyclers.

The printed circuit board of a typical mobile phone weighs 15-43% by weight. The weight percentage of precious metals in PCB is less than 1% but its momentary value among PCB material is 80%. The presence of metals in printed circuit boards has been studied by various authors with different methodologies. The metals in mobile phones may be categorized as precious metals (Au, Ag), platinum group metals (Pd, Pt, Rh, Ir and Ru), base metals (Cu, Al,Ni, Sn, Zn and Fe), hazardous metals (Hg, Be, In, Pb, Cd, As and Sb), scarce or trace metals (Te, Ga, Se, Ta and Ge) as pointed out in Khaliq et al. (2014). The typical medium grade PCB in 2002 contained 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 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 et al.,2012). The composition of a PCB varies from model to model of each brand. Many studies focus on recoverable metals in mobile PCBs. It is revealed that the concentration of precious metals in one ton mobile phone is 3573 g silver, 368 g gold and 287 g palladium respectively (Chancerel et al., 2009). A study found that 1000 million units of cell phones contain 250 tons silver, 24 tons gold, 9 tons Palladium and 9000 tons Copper (Hageluken, 2008). Another study revealed that 1000 kg of PCBs contain recoverable metals such as gold (279.93 g), precious metals – Pt, Pd, In (93.31 g), Copper (190.512 kg), Aluminium (145.152 kg), Lead and tin (30.844 kg) and silver (450 g) (Kumar and Shah, 2014). It is also predicted that 6000 mobile sets weighing one ton approximately would contain 130 kg Copper (United Nations University, 2009). Hence; the metals of interest for recovery in mobile phone are copper, gold, silver, palladium and ferrous metals.

2.7.5 Metal Recovery through Metallurgical Processes

There are three main technologies for recovering metals from WEEE – pyrometallurgy, hydrometallurgy, biohydrometallurgy. The vast majority of the industrial metal recovery processes for WEEE use physical pretreatment and pyrometallurgical processes, and to a smaller extent hydrometallurgical processes (Cui and Zhang, 2008). Physical separation is a common technique to process all types of WEEE. However, the one size-fits-all approach proves inefficient for such a complex type of waste. Moreover, high energy consumption, relatively low efficiency, as well as loss and contamination by metals are important obstacles in physical processing of WEEE for metal recovery (Chancere et al., 2009; Zhang et al., 2015). Thermodynamic limitations necessitate novel liberation and separation strategies, particularly for the metals embedded in the non-metal components (Ueberschaar and Rotter, 2015). Pyrometallurgical processes, encompassing smelting and pyrolysis, require the heating of WEEE at very high temperatures (up to 1500°C) to separate materials. Hydrometallurgical treatments comprise the use of leaching agents in aqueous solutions, such as strong acids (e.g. sulfuric acid, nitric acid, hydrochloric acid) and/or bases (e.g. sodium hydroxide and sodium hypochlorite) often applied together with oxidants (e.g. hydrogen peroxide and ferric iron) and complexing agents (e.g. cyanide and thiosulfate). Biohydrometallurgy is based on similar principles where the lixiviants are biologically produced. The leaching rates of hydrometallurgical processes are relatively faster than those of biohydrometallurgical processes, whereas biological processes are more environmentally friendly and cost-effective (Ilyas and Lee, 2015). Microbes that can adapt to toxic conditions, e.g. eventually increase their metal tolerance, are used in biohydrometallurgical processes (Navarro et al., 2013).Mechanical pre-treatment serves to prepare and optimize the e-waste feed for subsequent metallurgical treatment.

2.7.5.1 Pyrometallurgy

Smelting: Smelting is currently the industrial best available technology (BAT) and a few full-scale WEEE processing plants are already in operation. At Boliden Rönnskär smelters (Skelleftehamn, Sweden), discarded PCB are directly fed into a copper converter to recover Cu, Ag, Au, Pd, Ni, Se and Zn (Ghosh et al., 2015). At Umicore's integrated metal smelter and refinery in Hoboken (Belgium), PCB are first treated in an IsaSmelt furnace to recover precious metals. It is further refined with hydrometallurgical processes and electrowinning (Zhang and Xu, 2016). In the Ausmelt TSL reactor of Outotec (Espoo, Finland), WEEE is processed in copper/lead/zinc smelters in a combined process to recover Zn, Cu, Au, Ag, In, Pb, Cd, and Ge (Ebin and Isik, 2016).

Disadvantages of Smelting: (i) high energy consumption (ii) low selectivity towards desired metals (iii) emission of SO_2 and liberation of toxic heavy metals (Cappuyns et al., 2006; X. Zhang et al., 2012). (iv) emission of dioxins due to presence of flame retardants (Mäkinen et al., 2015) (v) unsuitable for a large range of WEEE due to low calorific value (Sun et al., 2015)

Pyrolysis: Pyrolysis of discarded PCB, carried out at elevated temperatures up to 900°C in the presence of inert gases, generates 23% oil, 5% gases and 70% metal-rich residue (Hall and Williams, 2007). As such, discarded LCD panels are subjected to pyrolysis in ceramic ovens at 700°C, and the organic-rich polarizing film is converted into pyrolysis oil and gas, whereas the liquid crystal is eliminated through deformation and detoxification of the hazardous substances under high temperature conditions (Ma and Xu, 2013).

Disadvantages of Pyrolysis: (i) high energy and reagent consumption (ii) formation of toxic compounds at high temperatures

All in all, even though pyrometallurgical techniques are highly economical, they have some glaring disadvantages which have slowly driven them out of use. These are as follows: -

- Recovery of plastics is not possible because plastics replace coke as a source of energy;
- Iron and aluminum recovery are not easy as they end up in the slag phase as oxides;
- Hazardous emissions such as dioxins are generated during smelting of feed materials containing halogenated flame retardants. Therefore, special installations are required to minimize environmental pollution;
- A large investment is required for installing integrated e-waste recycling plants that maximize the recovery of valuable metals and also protect the environment by controlling hazardous gas emissions;
- Instant burning of fine dust of organic materials (e.g., non-metallic fractions of e-waste) can occur before reaching the metal bath. In such cases, agglomeration may be required to effectively harness the energy content and also to minimize the health risk posed by fine dust particles;
- Ceramic components in feed material can increase the volume of slag generated in the blast furnaces, which thereby increases the risk of losing PMs from BMs;
- Partial recovery and purity of PMs are achieved by pyrometallurgical routes. Therefore, subsequent hydrometallurgical and electrochemical techniques are necessary to extract pure metals from BMs;
- Handling the process of smelting and refining is challenging due to complex feed materials. The expertise in process handling and the thermodynamics of possible reactions will be difficult.

2.7.5.2 Hydrometallurgy

Hydrometallurgical metal recovery processes involve an oxidative leaching for the extraction of metals, followed by separation and purification procedures (Schlesinger et al., 2011). It has advantages over pyrometallurgy such as lower toxic residues and emissions, and higher energy efficiency. However, these processes still pose a threat due to the use of large amounts of toxic, corrosive and flammable reagents and the generation of high volumes of effluents and other solid wastes (Tuncuk et al., 2012).

Oxidative Acid Leaching: Acid leaching of metals from WEEE has been investigated using various acids and oxidants, or mixtures thereof. It is an essential process when extracting valuable metals from PCB (Ghosh et al., 2015), indium from ITO glass (Zhang et al., 2015) and neodymium from HDD (Li et al., 2009). In oxidative acid leaching, the important parameters are temperature, concentration and contact time with the former being the most important. The leaching of metals in various oxidative acidic media has been investigated for their effectiveness in metal recovery from waste PCB, including hydrochloric acid (Jha et al., 2012), sulfuric acid (Kumar et al., 2012), nitric acid (Joda and Rashchi, 2012), sodium hypochlorite (Akcil et al., 2015), thiosulfate (Ha et al., 2010), thiourea (Jing-ying et al., 2012) and halides (Syed, 2012).

Cyanide leaching: Cyanide leaching is the industrial norm for the leaching of precious metals from their primary ores (Zhang et al., 2012). It interacts with nearly all transition metals, except lanthanides and actinides, and forms complexes with high chemical stability (Marsden and House, 2006). Out of the 875 gold and silver mines operational in 2000, more than 90 used cyanide as lixiviant (Akcil et al., 2015). Cyanide is preferred because of its cost-effectiveness. However, effluent treatment is problematic as high cyanide concentrations are lethal to most forms of life. Consequently, several non-cyanide leaching processes (see below) have been developed considering the toxic nature and handling problems of CN-. However, none of them has yet proven more cost-effective than cyanide at full-scale operation (Akcil, 2010).

Thiosulfate leaching of gold: Au leaching with thiosulfate (S2O32−) is a non-toxic alternative to cyanidation for primary (Grosse et al., 2003) and secondary (Akcil et al., 2015) ores. S2O32− leaching attracted interest as an alternative precious metal leaching agent owing to its environmental advantages (Zhang, 2008). Thiosulfate leaching can be considered as a non-toxic process, and the gold dissolution rates can be faster than conventional cyanidation (Aylmore and Muir, 2001). In alkaline or near neutral solutions of thiosulfate, Au dissolves in the presence of a mild oxidant. The Au leaching rates can be faster than conventional cyanidation and there is a lower interference from other cations high yield can be obtained. Moreover, the process could becomemore cost-effective than cyanidation (Abbruzzese et al., 1995; Aylmore and Muir, 2001).Several studies investigated the leaching of precious metals from waste PCB, such as the effectof the $S_2O_3^{2-}$concentration, alkalinity agent (e.g. NH4OH) and catalyzing agent (e.g. Cu2+ions)(Ficeriová et al., 2011; Ha et al., 2010; Petter et al., 2014). Similar to cyanide, dissolved coppermay adversely affect the leaching process due to the decomposition of $S_2O_3^{2-}$.The reaction thenbecomes relatively inefficient and slow at ambient temperatures. High consumption of theleaching agent, its chemical instability and low cost-effectiveness are the main bottlenecks ofthis process to be applied to WEEE (Akcil et al., 2015).

Thiourea leaching of gold: Thiourea ($SC(NH_2)_2$) is an organosulfur compound that forms white crystal complexes with many transition metals. Under acidic conditions, with the presence of an oxidant such as ferric iron (Fe^{3+}), thiourea and gold will form soluble cationic complexes with Au (Li and Miller, 2007). The rate of gold dissolution is strongly determined by pH. The role of ferric iron in the complexation process is to facilitate the oxidation of metallic gold (Au^0) to the aurous (Au^+)ions (Gurung et al., 2013). Several strategies including supply of an additional oxidant or a two-step leaching procedure were proposed for the leaching of precious metals by $SC(NH_2)_2$ (Behnamfard et al., 2013; Jingying et al., 2012). Elevated temperatures are inefficient due to poor thermal stability of the reagent (Gurung et al., 2013). The high cost and chemical instability of $SC(NH_2)_2$ are challenges for the development of a scaled-up process.

Halide leaching of gold: The halides iodine (I_2) and chlorine (Cl_2) can act as redox, complexing and precipitating agents under certain conditions. This property gives them an advantage to achieve selective recovery of PGM from waste materials (Serpe et al., 2015). Several approaches including leaching of metals using electro generated chlorine (Kim et al.,2011b), Au leaching using an iodine hydrogen peroxide (I_2 - H_2O_2) system (Sahin et al., 2015),and I^-/I_2 leaching of gold in a three-step leaching system (Serpe et al., 2015) have beeninvestigated. Despite the fast kinetics and high efficiencies of this method, very high rates ofreagent consumption and reagent costs are the main obstacles of this process.

Khaliq et al. (2014) summarized precious metal recovery from e-waste by hydrometallurgical route in Table 2.17.

Table 2.17: Summary of Hydrometallurgical Recovery of Precious Metals from WEEE

Investigators	Leaching agent	Process conditions	Recovered metals
Park and Fray [41]	Aqua regia	Ratio of metals to leachant = 1:20 g/mL	Au, Ag and Pd
Sheng and Estell [49]	HNO_3 (1st stage), epoxy resin (2nd stage), and aqua regia (3rd stage)	Extraction was carried out in the three stages (self agitation)	Au
Quinet *et al.* [50]	H_2SO_4, chloride, thiourea and cyanide leaching	Leaching & metals recovery by cementation, precipitation, ion exchange and carbon adsorption	Au, Ag, Pd and Cu
Chielewski *et al.* [51]	HNO_3 and aqua regia	Roasting of e-waste in the presence of carbon; leaching with HNO_3 and aqua regia; and solvent extraction with diethyle malonate	Au
Zhou *et al.* [52]	HCl, H_2SO_4 and $NaClO_3$	Combustion of e-waste at 400–500 °C followed by leaching	Ag, Au and Pd
Kogan [53]	HCl, $MgCl_2$, H_2SO_4 and H_2O_2	Dissolution of e-waste in different solvents and leaching conditions; and recovery of metals in stages	Al, Sn, Pb and Zn (1st stage), Cu and Ni (2nd stage), Au, Ag, Pd and Pt (last stage)
Veit *et al.* [11]	Aqua regia and H_2SO_4	Mechanical processing and then dissolution of e-waste in different solvents	Cu
Mecucci and Scott [54]	HNO_3	Electrochemical deposition of Cu at cathode from solution	Pb and Cu

Hydrometallurgical processes have the following disadvantages which have prevented their widespread adoption: -

- Slow and time consuming
- Mechanical processing of e-waste takes longer to reduce size for efficient dissolution. It is reported that 20% PM is lost by mechanical force during the liberation process that contributes to a significant loss in the overall revenue.
- Cyanide is a dangerous leachant and can contaminate nearby water-bodies, thus jeopardizing aquatic wildlife and human consumers
- Halide leaching is difficult to implement due to strong corrosive acids and oxidizing conditions. Specialized equipment made of stainless steel and rubbers is required for leaching of gold using halide agents from e-waste.
- The use of thiourea leachants is limited in gold extraction due to its high cost and consumption. Moreover, further developments are required to improve the current technology of thiourea-based gold leaching.

- The consumption of thiosulfate is comparatively higher and the overall process is slower, which limits its application for gold extraction from ores as well as from e-waste.
- There are risks of PM loss during dissolution and subsequent steps, therefore the overall recovery of metals will be affected.

2.7.5.3 Biohydrometallurgy

Biohydrometallurgy, the use of microbes to process metals, is an efficient technology to produce metals from primary ores. In the context of metal processing, biohydrometallurgy is defined as a blend of biotechnology and metallurgy (Ilyas et al., 2015). It is an established technology to process many metals including copper (Cu), gold (Au), cobalt (Co), nickel (Ni), zinc (Zn), arsenic (As), molybdenum (Mo), cadmium (Cd), and uranium (U) (Watling, 2015). More than 15% of the total annual 15 Mtons of Cu, 2.35 ktons of 5% Au, along with a small fraction of Ni and Zn are produced using biohydrometallurgical routes (Johnson, 2014; Schlesinger et al., 2011). Biohydrometallurgy uses acidophilic bacteria, cyanogenic heterotrophs and/or acid-producing heterotrophs to selectively recover metals from waste streams. Full scale biomining applications compensate high initial capital investments with lower operating costs over a long period (Brierley and Brierley, 2013). Furthermore, biotechnology relies on natural material cycles in more environment friendly processes than conventional metal extraction techniques. Biotechnological approaches will play a significant role in the treatment of wastes for metal recovery in the future (Lee and Pandey, 2012). Despite the relative slower kinetics compared to conventional methods, bioleaching has matured into a well-developed technology operated in advanced engineered systems. Biomining of low-grade ores, and in particular Cu, made a useful case study for bioprocessing of metals, which is expected to be the future trend for non-sulfide metal-rich wastes such as WEEE (Orell et al., 2010).

Finally, Table 2.18 compares pyrometallurgy, biohydrometallurgy and hydrometallurgy in terms of different feasibility criteria.

Table 2.18: Overview of Pyrometallurgy, Hydrometallurgy and Biohydrometallurgy

Parameters	Pyrometallurgy	Hydrometallurgy	Biohydrometallurgy
Environmental Impact	High, due to gaseous emissions	Moderate, due to toxic chemicals	Low
Selectivity	Low, only a fraction of metals	High	High
Economics	Capital intensive, low job creation	Low capital, high operating cost	Low investment and operating costs
Social acceptance	Low	Medium, some toxic reagents and end products	High, cleaner processes and auto-pollution control
Energy	Very high	Low, ambient conditions	Low to none
Final residue	High	Low	Low to none
Process conditions	Harsh thermal treatment conditions	Harsh corrosive acids	Safe conditions, low to non-toxic chemicals
Level of advancement	High, established full-scale technology	Medium, many pilot scale demonstrations	Low TRL, no pilot scale study
Advancement requirement	Abatement of environmental impacts	Selectivity towards individual metals, scale-up studies	Fundamental research, scale-up studies
Feasible applications	Low, only high grade WEEE	High, all metals and their alloys	Medium, restrictions due to toxicity on bacteria

Chapter 3

Methodology

3.1 INTRODUCTION

The present research has three components — estimation of volume of e-waste generation, assessment of its impacts on health, safety and environment, and examination of the potential for recovery of precious metals from e-wastes. Different approaches have been adopted in the present study depending on the objectives. The first approach was to collect and review the relevant literatures and past studies on e-wastes (Chapter 2). Although it was stated in the ToR of this project that the research would be based solely on secondary data, after reviewing the existing studies on e-wastes in Bangladesh, it was concluded that only few such studies have so far been carried out in Bangladesh and they are not sufficient for the purpose of carrying out the current study. A few studies (mainly ESDO and Waste Concern-Retem) endeavored to address the e-waste scenario in Bangladesh. However, data in these studies show a significant variation. Some of these studies considered only a few items of e-wastes and some covered only Dhaka City (DSMA). Considering these, it was concluded that only secondary data would not be reliable and sufficient to estimate and establish the trend of e-waste generation in Bangladesh. As such, it was decided that both primary and secondary data on e-wastes would be collected to achieve the objectives of this research project. The following sections in this chapter present the overall methodology adopted in this study to achieve the stated goals. Subsequent chapters of this report (Chapters 4, 5 and 6) present the detailed approaches undertaken to carry out the specific tasks along with the corresponding outcomes.

3.2 METHODOLOGY

3.2.1 Estimation of E-Waste Generation

To estimate the e-waste amounts and establish a trend of generation, both primary data and secondary data have been collected for different EEE items. Eight such items have been selected for this study; electric fans, fridge, air conditioner, CFL bulbs, TV, IT equipment, cell phones and computer (Table 3.1).

Table 3.1: Selected Items for Waste flow Estimation

Sl No.	Item
1	TV
2	AC
3	Computer
4	Mobile phone
5	IT equipment
6	CFL Bulb
7	Fridge
8	Electric fan

Dhaka city has been selected as the study area for collection of primary data on e-wastes. The study locations within Dhaka City have been selected considering the organized and unorganized market places and shops where e-waste items are unloaded, traded, dismantled, recycled, reused, repaired, processed and disposed of. These locations were identified through a transect walk and test surveys in the area. Primary data has been collected from these locations through questionnaire survey and interviews (Annex A). These locations are Elephant Road, Nimtoli, Chankhar Pool and Motijheel (Figure 3.1). Data have been collected from the e-waste collectors and the recycling shop owners, dealers and Bhangari Shops.

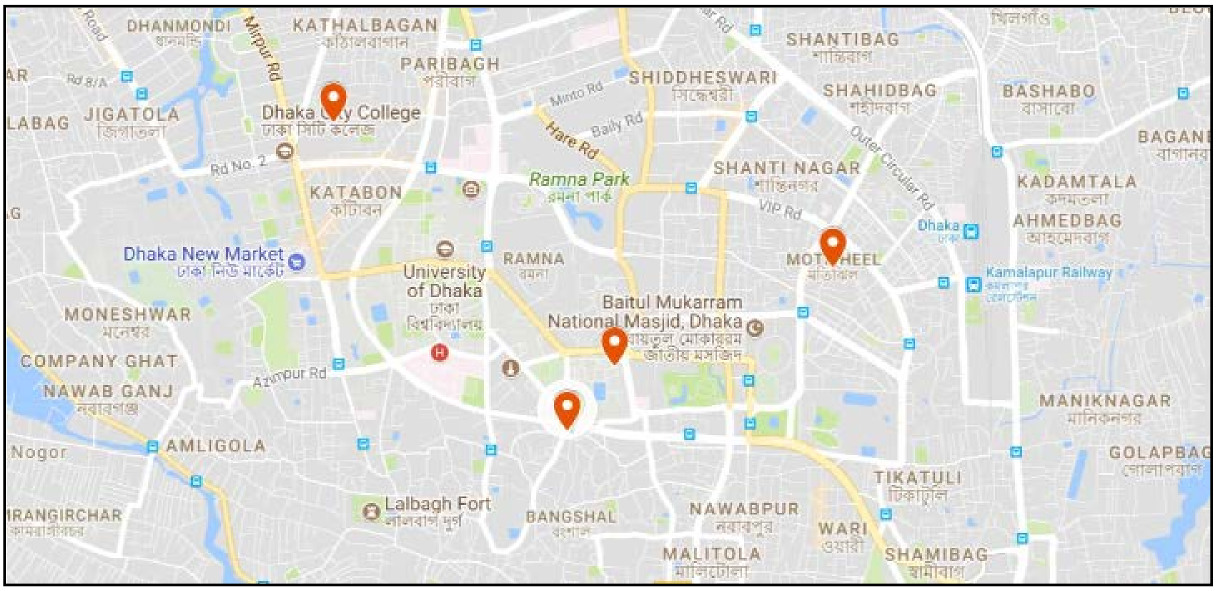


Figure 3.1: Survey locations within Dhaka city

Besides, data were also collected from recyclers, e-waste exporters, electrical and electronic equipment importers, business entities and NBR. The research team visited and met relevant agencies, individuals and establishments dealing with repairing, assembling, dismantling and sale of e-wastes. Apart from these visits, two recycling organizations and a two Ship Recycling Industries were also visited to understand their activities and collect data (Chapter 4). Volumes of e-wastes for selected EEE items have been estimated by mathematical models based on past and historical sale/import data. The amount of wastes that go to bhangari shops, e-wastes dealers and recyclers have also been estimated using primary data. The flow chart (Figure 3.2) outlines the methodology adopted in estimation of e-waste volume and the forecast future trend in Bangladesh. Detailed description of the method of estimation is presented in Chapter 4.

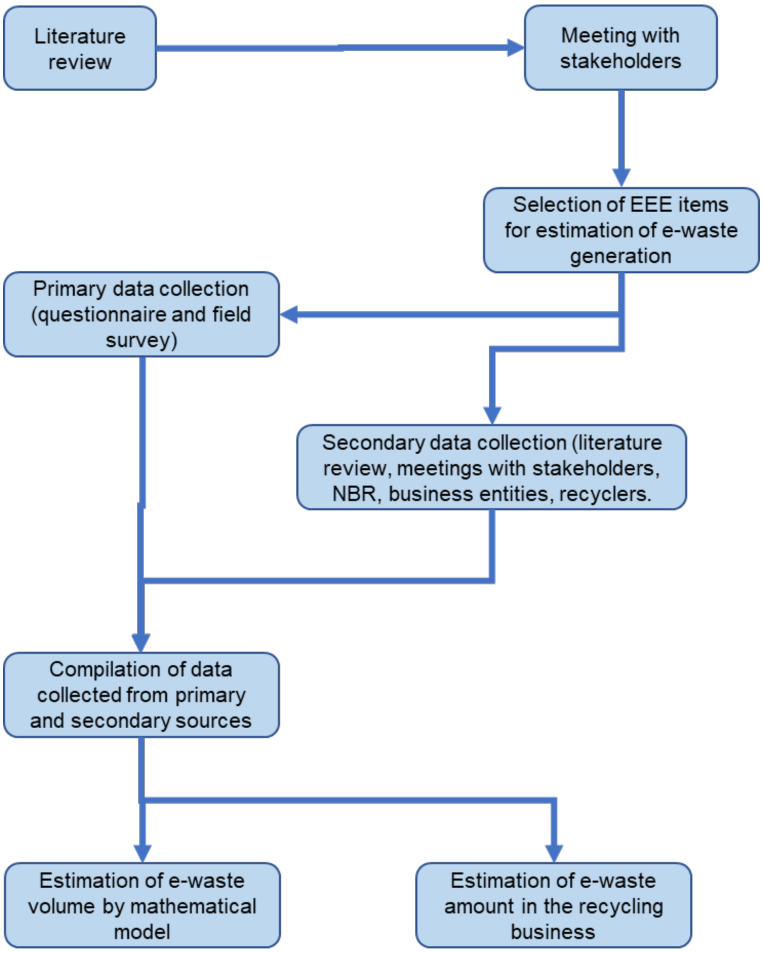


Figure 3.2: Flow Chart showing the methodology adopted in E-waste Estimation

3.2.2 Assessment of Impacts of E-Wastes on Human Health and Environment

Improper ways of handling, dismantling, recycling and recovering of e-waste poses serious threat to the environment and health. It is already established in the existing the literature that hazardous elements in e-waste causes air, soil and water pollution and occupational health hazards (Chapter 2). However, establishing a conclusive and definite link between e-waste and any adverse health impacts requires clinical data of the exposed workers and population, Collection of such data is a very complex process and as a result those data are not available. Considering this constraint, the present study has attempted two approaches to assess such health impacts. First approach is a direct one where questionnaire and field survey has been conducted at the selected survey locations (Figure 3.1) among the workers involved in the handling and recycling activities of e-wastes. In this approach, the objective was to know the awareness level of the workers about impacts of e-wastes and any health-related problems due to handling of e-wastes. Another is an indirect approach; health risk analysis of the exposed workers involved in this occupation through inhalation and ingestion of toxic chemicals. Risk analysis has been carried out following USEPA Guidelines (1989). Figure 3.3 shows the flow diagram of the methodology adopted in impact assessment. Details of the risk analysis method is presented in Chapter 5.

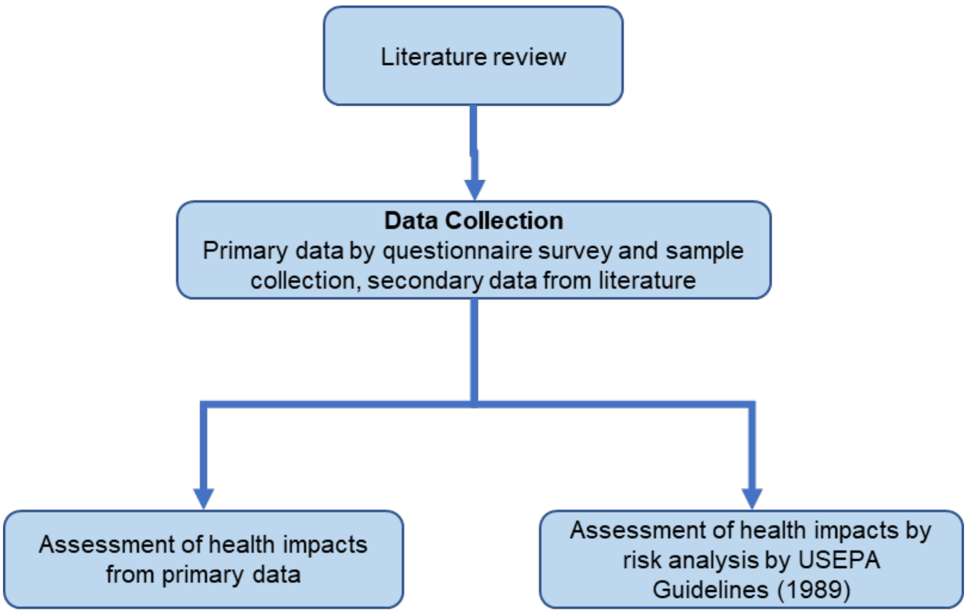


Figure 3.3: Flow chart of Methods Adopted in Impact Assessment of E-Wastes

3.2.3 Investigation of Potential Recovery of Value Metals from E-Wastes

E-waste contains precious metals (Gold, Silver, Platinum etc.) as well as hazardous toxic metals (Mercury, Chromium, Cadmium, Lead etc.) (Sec.2.2, Chapter 2). Metal extraction from e-waste is more efficient than mining from ores. All over the world such metal extractions are performed to recover the value metals from the wastes. In developed countries, scientifically proven technologies are being used to recover the precious metals, whereas in developing countries, this metal extraction processes are performed in rudimentary ways, thereby risking the environment and human health.

In the present study, an attempt has been undertaken to recover the value metals from e-wastes. For this purpose, e-waste samples (mobile phone and computer PCBs, RAM, etc.) were collected from different locations including Elephant road, Nimtoli, Motijheel and Narayanganj (Figure 3.4).

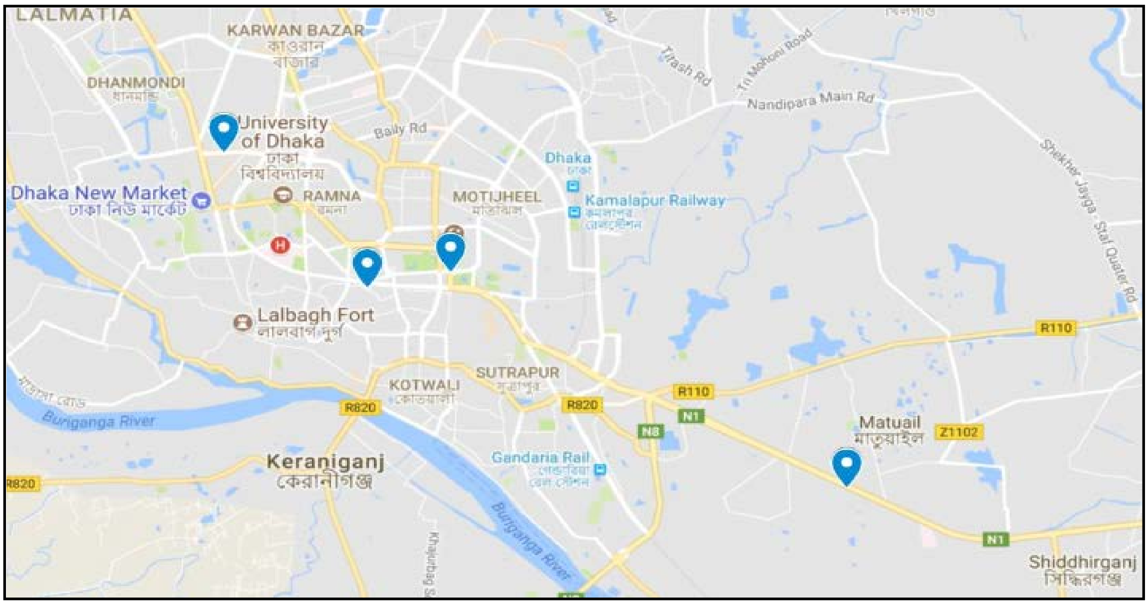


Figure 3.4: E-Waste Sample Collection Locations

Extraction of value materials are usually performed using three extractive metallurgical processes. These are as follows: Electrometallurgy, Hydrometallurgy and Pyrometallurgy. Electrometallurgy helps to refine the metal and get it in a higher purified form. Hydrometallurgy has reputations as a green process. In recent times, pyrometallurgy is the most practiced one in large scales. However, this process emits hazardous gases and smokes as by products, and therefore hydrometallurgy process has been adopted to recover the metals in the present study (Table 2.18 in chapter 2 describes the advantages of hydrometallurgy over pyrometallurgy). Figure 3.5 shows the flow diagram of the value metal recovery process from e-waste followed in the present study. Significant amount of valuable metals was present in the waste PCBs/RAMs. Four different metals Gold (Au), Silver (Ag), Copper (Cu) and Tin (Sn) were recovered through hydrometallurgical processes. The methods adopted in the recovery process of metals, analysis and results are discussed in detail in Chapter 6.

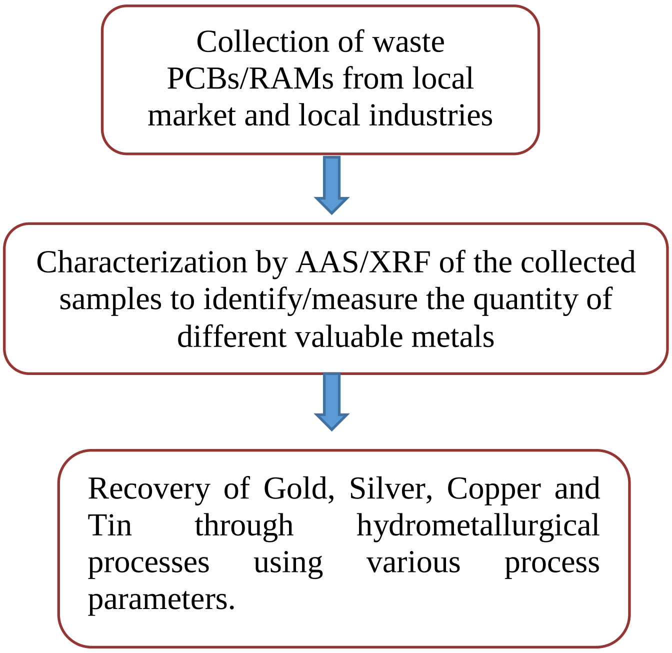


Figure 3.5: Methodology used for value metal recovery from e-wastes

Chapter 4

Estimation of E-Waste Generation

4.1 INTRODUCTION

One of the main objectives of this research is to evaluate the available data on the amount of e-wastes in Bangladesh and estimate the trend of its future generation.Although there exists a number of researches in e-wastes generation in Bangladesh, neither of them isextensive and covers all items nor for the entire Bangladesh. Moreover, the published data of various sources varies in a wide range. The present chapter identifies the major items of e-wastes in Bangladesh, evaluates the data on these items of various sources, estimates the amount and generation trend for year 2020, 2025, 2030 and 2035. The present study collected secondary data of consumption of electronic equipment from various sources and has made an estimation of its waste generation using this data by mathematical model. The study also collected primary data on e-wastes from different sources such as waste generators, recyclers, collectors, exporters and has also made an estimation of e-wastes in the waste stream by collating all these primary data.

4.2 ESTIMATION OF E-WASTE AND ITS FUTURE TREND

It is important to have a gauge of e-waste streams. There exists a number of methods of e-waste estimation such as Market Supply Method, Material Flow Analysis, Consumption Use Method, Econometric Analysis etc. Unlike the conventional municipal solid waste (MSW), e-waste has different end points for the same good and also varied discarding patterns. Therefore, it is difficult to assess what is the waste generation rate from any particular item of electronic gadget. For instance, a PC bought would have an average life span of 5 years. However, users of PCs would show varying patterns of discarding it after its life span is over. Some may continue to use it beyond its lifetime; others may donate it where it is used further for some years. Some may keep it in store and others may pass it on to someone else. Some would use the useful parts for refurbished PCs and others may be subjected to material recovery and final disposal.This invariably makes the estimation more complicated and approximate. The above mentionedmethods estimate e-wastes in approximation and the most important issue is the dearth of availability of data for the estimation, specially for developing countries.

Generation of E-waste statistics can be determined by using different indicators: i) Total EEE put on the market, ii) Total E-wastes generated, iii) E-Waste officially collected and recycled and iv) E-waste collection rate. In developed countries, specially in EU countries where EPR, Take-Back System, e-waste collection system exist, data on such indicators are available but in developing country like Bangladesh, no such data are available.In the present study, Material Flow Analysis (MFA) method has been adopted to estimate the waste generated from electrical and electronic equipment and its future trend. Primary sales/import data of selected EEE items have been collected and End of Life (EOL) concept is used to estimate the amount of e-waste generated from these items.

Product's End of Life (EOL) Span:

End of Life (EOL) is the life span of products or when the product reaches its end of life (EOL).It is very difficult to assume EOL because it depends on many factors such as behavior, age, gender, scope and cost of repairing, affluence, fast rate of technological innovation etc. The total life span of any particular product will encompass several stages of use. The first use is the time period in which the product is considered functional to the first purchaser. When the product ceases to be functional to the first user, the product may be put in storage, discarded, or recycled. If it is in working order, however, someone else will most likely reuse it. This is referred to as the 'second use stage' There are many combinations of use, reuse, repairing, recycling before its final disposal. Annex B shows the assumed life span for the products and the percentage from the sales amount when the products reach their EOL.

Mathematical Model Study:

The model is based on the assumptions of the life span and past and future sales data for eight (Fan, TV, Air conditioner, Fridge, IT related equipment, Cell phones, Computers, CFL Bulbs) selected electronic products. The generated e-waste amount in the future is calculated based on EOL quantity with assumptions in their percentages, which is the same model concept used by the USEPA (USEPA, 2007, USEPA, 2008 and USEPA, 2009).

Model Input Data:

The model input data are the sales data (past and future sales data) and life span of the products (Annex B). First step is to generate future sales data based on the past data. The future sales data upto 2035 has been predicted for each item by polynomial regression analysis and the regression coefficient (R^2) value is also shown in the graphs.

Model Applied:

In a socioeconomic system, products flow into the market (sales) and then accumulate in the built environment (stock); when reaching EOL, after a certain period (life span), they flow out. The model presented in this study tries to estimate the future amount of e-waste in Bangladesh for a number of selected EEE items. The model is a material flow analysis model, which is widely used to estimate the amount of waste in current years or to predict the waste that will be generated in the future. The model inputs are the annual product sales/import data, past sales data, and future sales data.This secondary data of the selected items is collected from different sources such as NBR, Business Entities, Bangladesh Computer Samity (BCS), BBS (2015) and previous studies. The items for which very limited data were obtained, the historical data were generated using growth rate of those items. The sales/consumption of each items with time thus obtained are shown in Figures 4.1 to 4.8.

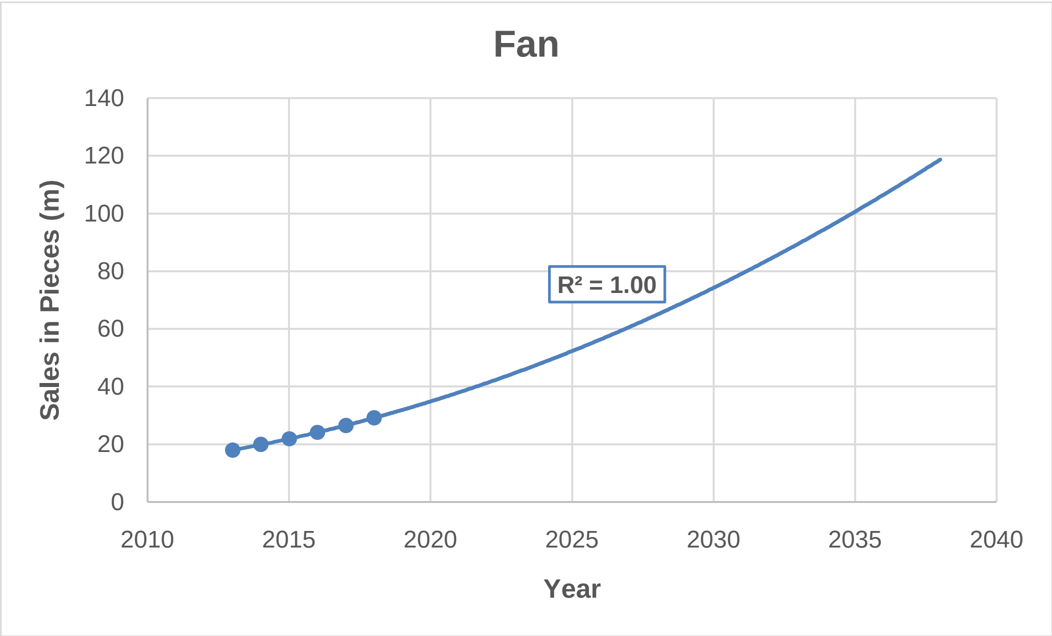


Figure 4.1: Sale of Fan (pieces) per Year

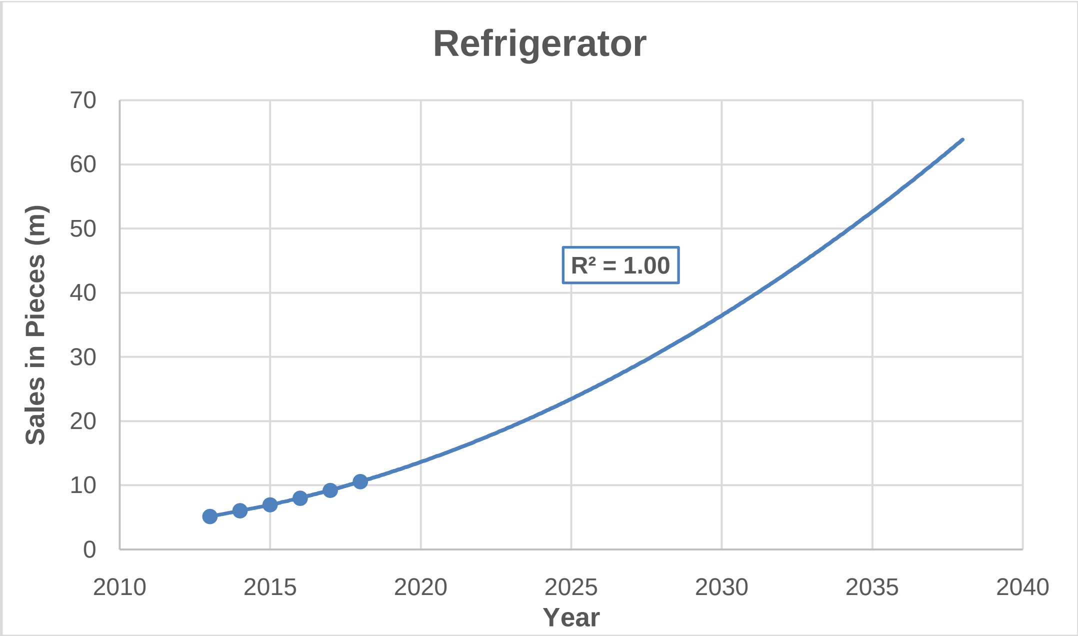


Figure 4.2: Sale of Refrigerator (pieces) per Year

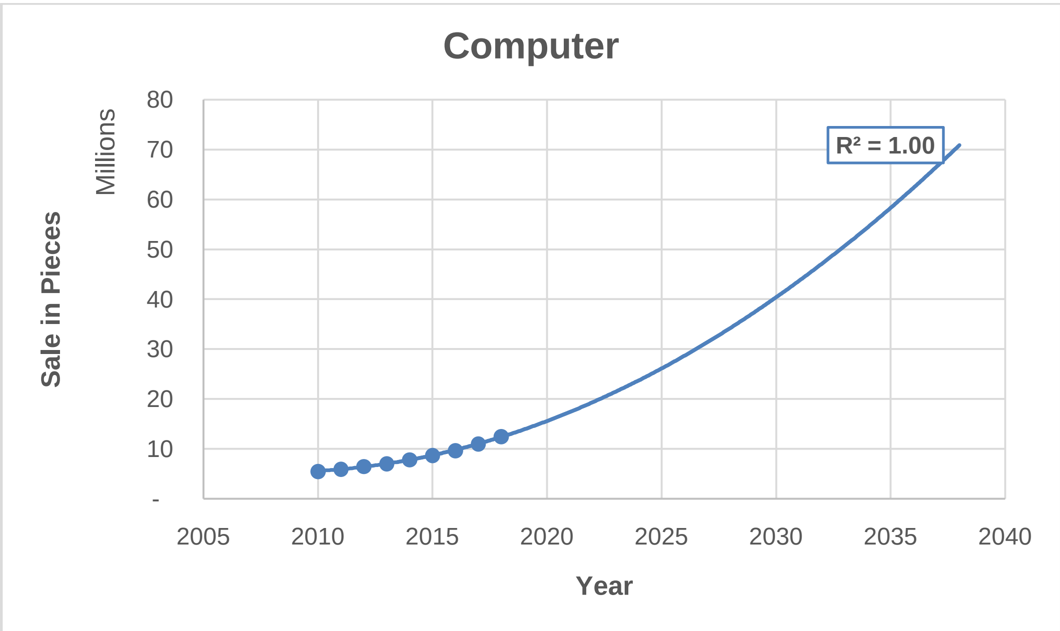


Figure 4.3: Sale of Computer (pieces) per Year

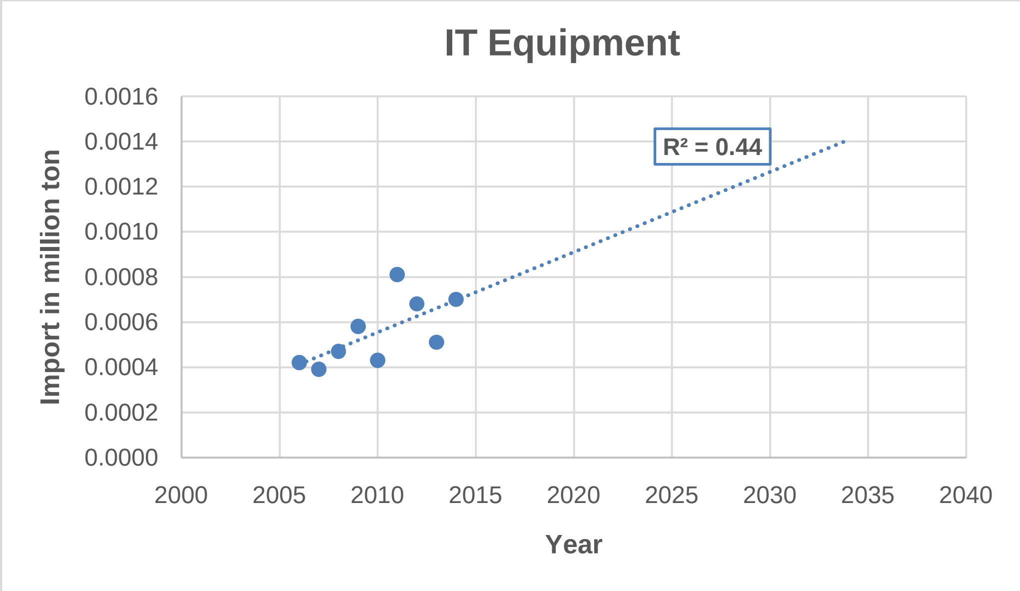


Figure 4.4: Import of IT Equipment (million ton) per Year

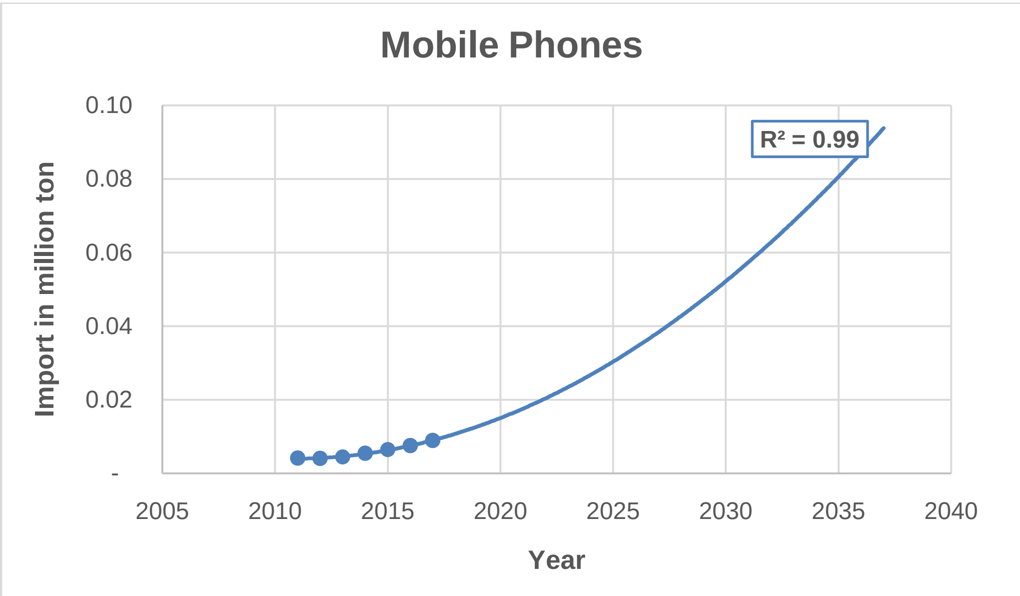


Figure 4.5: Import of Mobile Phones (million) per Year

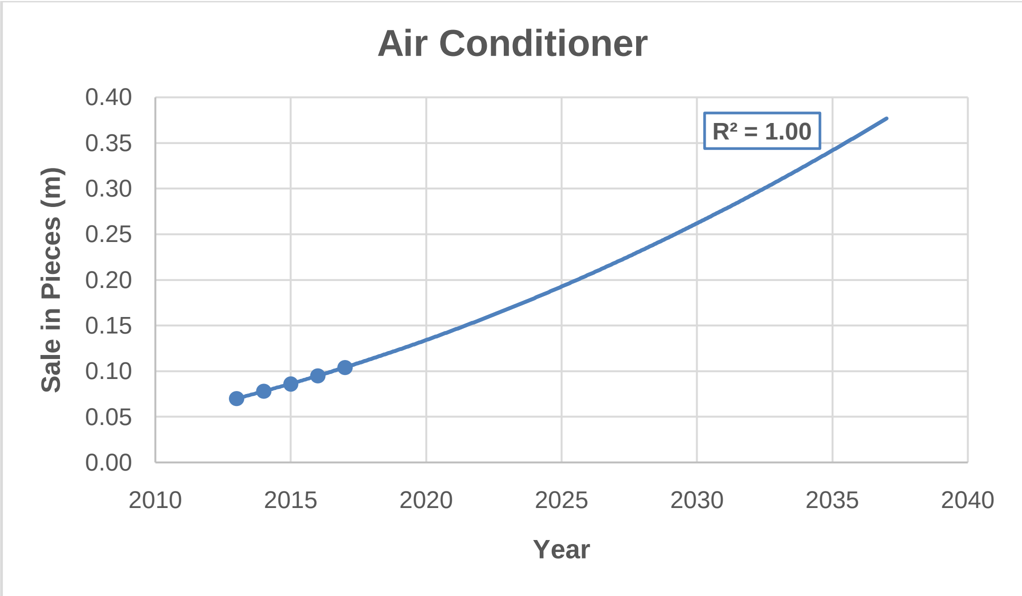


Figure 4.6: Sale of Air Conditioner (pieces) per Year

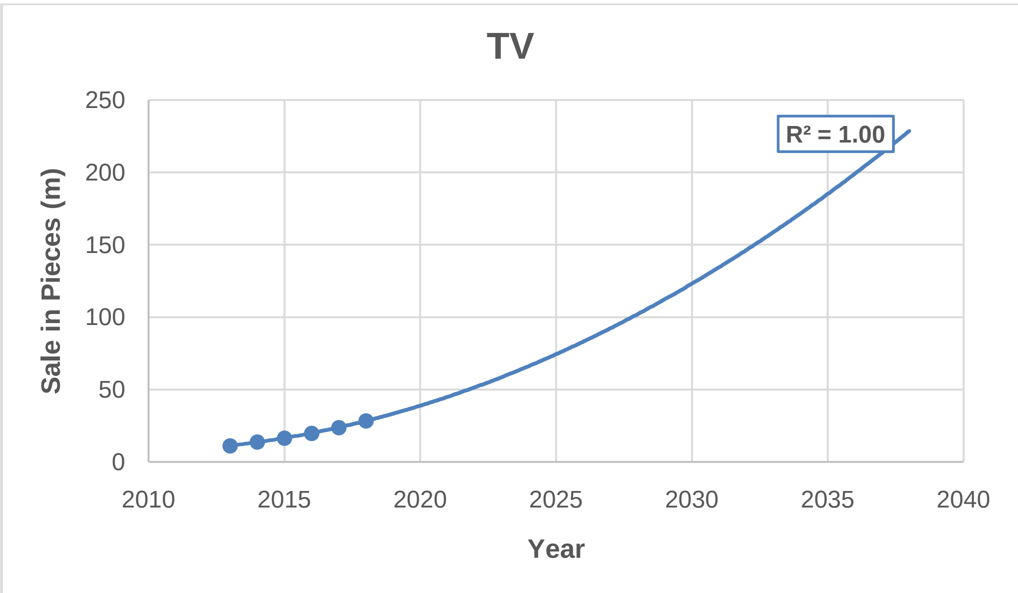


Figure 4.7: Sale of Television (Pieces) per Year

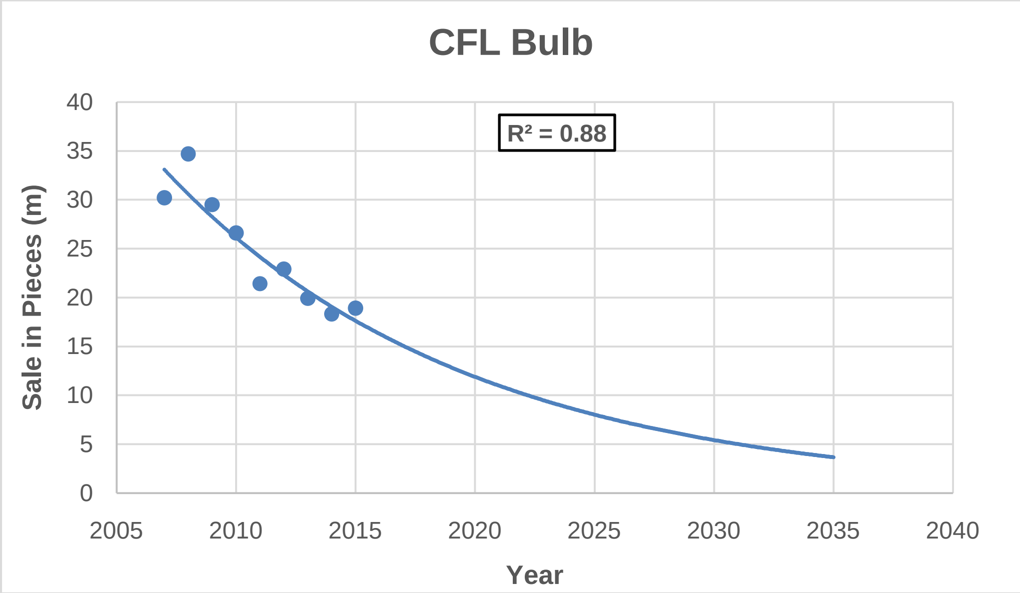


Figure 4.8: Sale of CFL Bulb (Pieces) per Year

In Material Flow Analysis (MFA), the general form used to represent the outflow after the useful life span is a function of the inflow in the past and can be expressed by Equation (1).

$$Outflow = \sum_i Inflow \times P \tag{1}$$

Where, the outflow represents the waste generated and the inflow represent the sales/import amount and (P) is the percentage amount when the product reaches its end of life. As for example, Equations (2) shows how the generated e-waste amount for computers are calculated.

$$W_{(COMPUTER)_n} = \sum_{i=7,9,12,15} (S_{n-7}) \times (25\%) + (S_{n-9}) \times (25\%) + (S_{n-12}) \times (25\%) + (S_{n-15}) \times (25\%) \tag{2}$$

Where,

$W_{(Computer\ )_n}$ = The amount of EOL generated from computers in year (n)

S = historical and future sales amount for computer.

Similarly, the following equations show the estimated wastes generated by TV, Air conditioner, Cell phones, IT related equipment, Electric Fan, and Fridge respectively.

$$W_{(TV)_n} = \sum_{i=8,11,15,17} (S_{n-8}) \times (25\%) + (S_{n-11}) \times (25\%) + (S_{n-15}) \times (25\%) + (S_{n-17}) \times (25\%)$$

$$W_{(AC)_n} = \sum_{i=10,15,20} (S_{n-10}) \times (80\%) + (S_{n-15}) \times (10\%) + (S_{n-20}) \times (10\%)$$

$$W_{(CP)_n} = \sum_{i=2,5,6} (S_{n-2}) \times (65\%) + (S_{n-5}) \times (30\%) + (S_{n-6}) \times (5\%)$$

$$W_{(IT)_n} = \sum_{i=7,9,12,15} (S_{n-7}) \times (25\%) + (S_{n-9}) \times (25\%) + (S_{n-12}) \times (25\%) + (S_{n-15}) \times (25\%)$$

$$W_{(FAN)_n} = \sum_{i=10,15,20} (S_{n-10}) \times (80\%) + (S_{n-15}) \times (10\%) + (S_{n-20}) \times (10\%)$$

$$W_{(Fridge)_n} = \sum_{i=10,15,20} (S_{n-10}) \times (80\%) + (S_{n-15}) \times (10\%) + (S_{n-20}) \times (10\%)$$

For CFL bulb, the EOL is considered as two years and after two years all the CFL bulbs were considered as wastes.

Using these equations, the wastes generated by the selected items have been estimated upto year 2035 and presented in the Figures 4.9 to 4.16. It is noted here that all the wastes are mentioned in Metric Ton. The items whose sales are in pieces, have been converted to equivalent weight by multiplying with the conversion factors. The conversion factors are shown in Table 4.1.The conversion factors are chosen from different websites (https://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SR_SB_CFL.pdf, http://www.movers.com/ask-moving-expert/q/how-much-does-a-flat-screen-tv-weigh-1402.html)

Table 4.1:Unit Weight of Each Item

Item	Unit Weight of Each Item (kg)
Mobile Phone	0.115
Computer	11.23
Television	29
Air Conditioner	52.5
Refrigerator	122
Fan	2.24
CFL Bulb	0.066

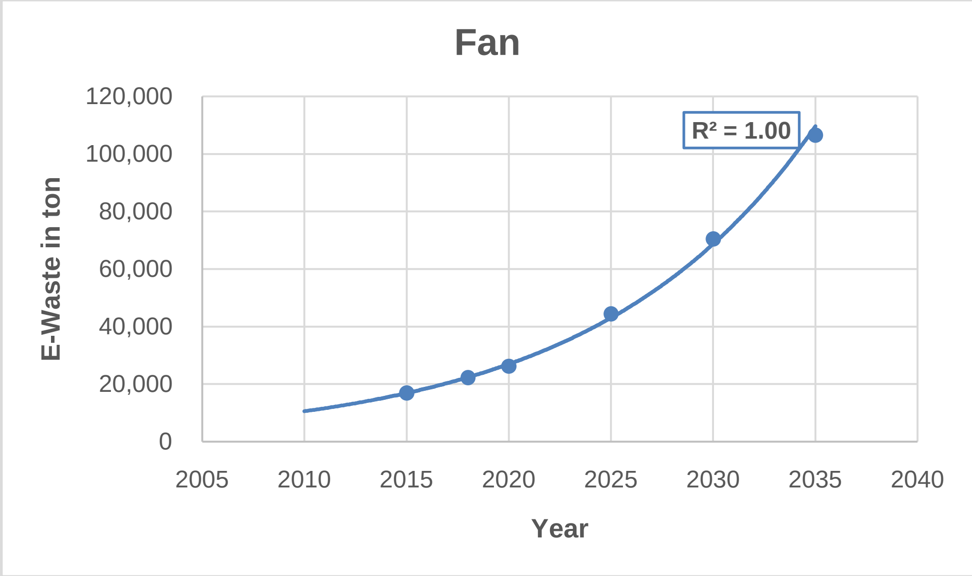


Figure 4.9: E-waste Generation (Fan) in Ton per Year

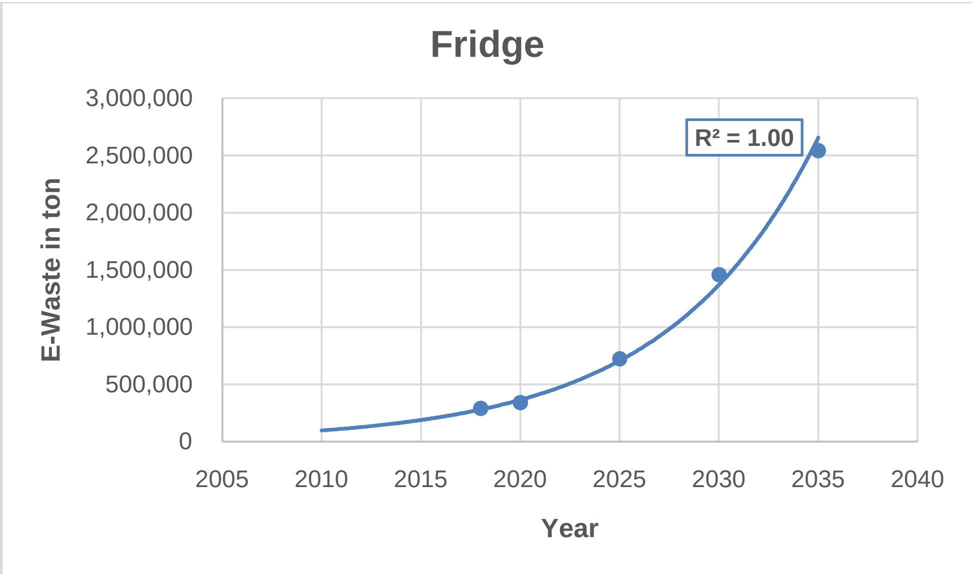


Figure 4.10: E-waste Generation (Refrigerator) in Ton per Year

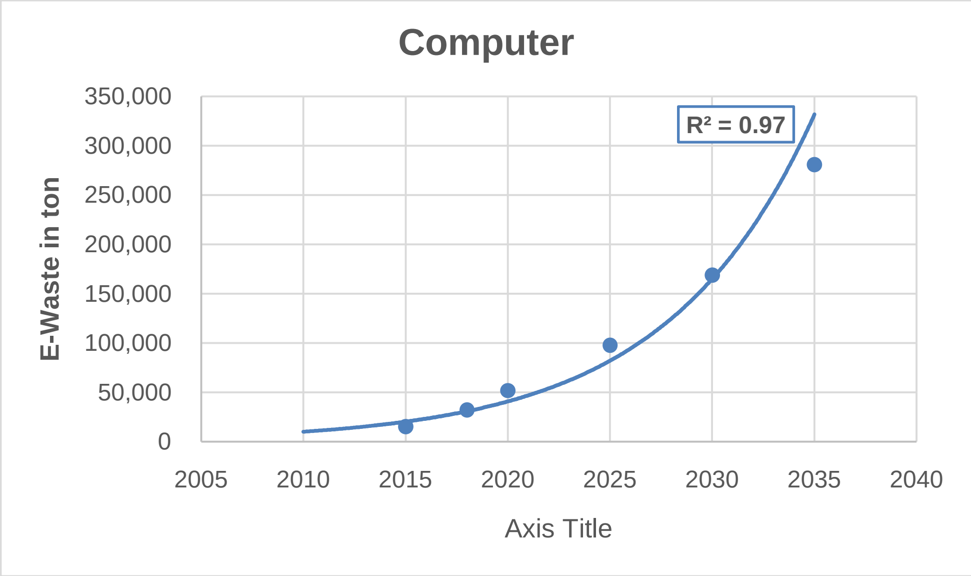


Figure 4.11: E-waste Generation (Computer) in Ton per Year

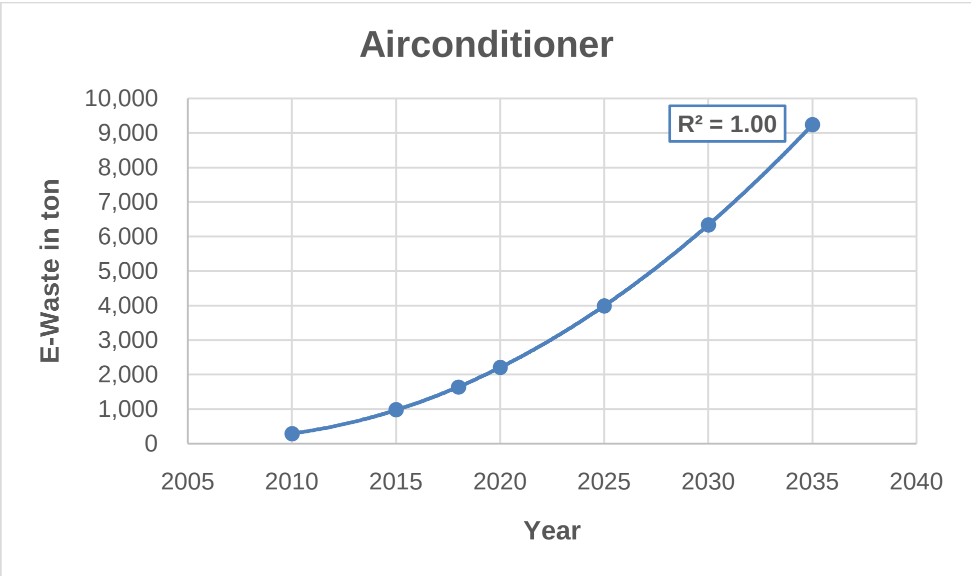


Figure 4.12: E-waste Generation (Air Conditioner) in Ton per Year

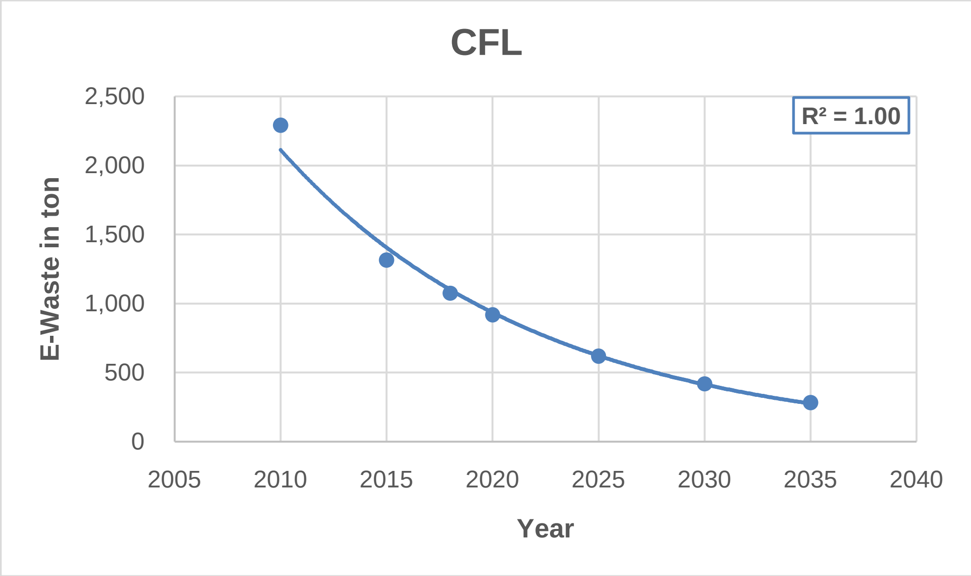


Figure 4.13: E-waste Generation (Fan) in Ton per Year

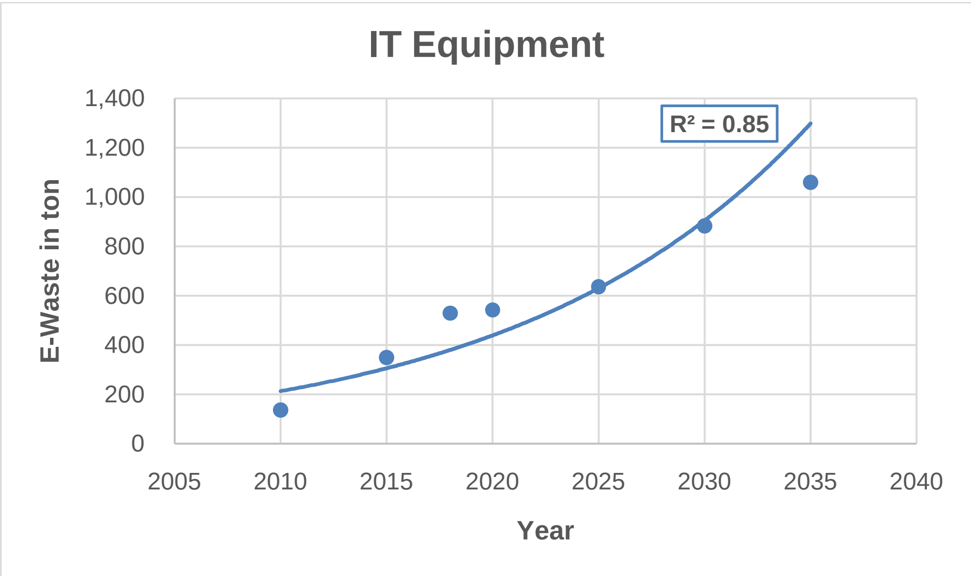


Figure 4.14: E-waste Generation (Fan) in Ton per Year

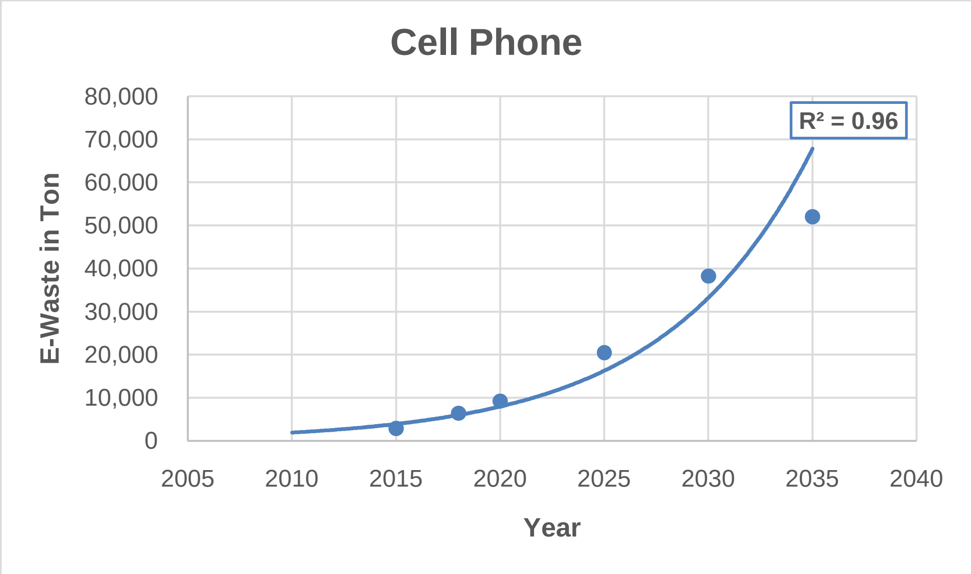


Figure 4.15: E-waste Generation (Fan) in Ton per Year

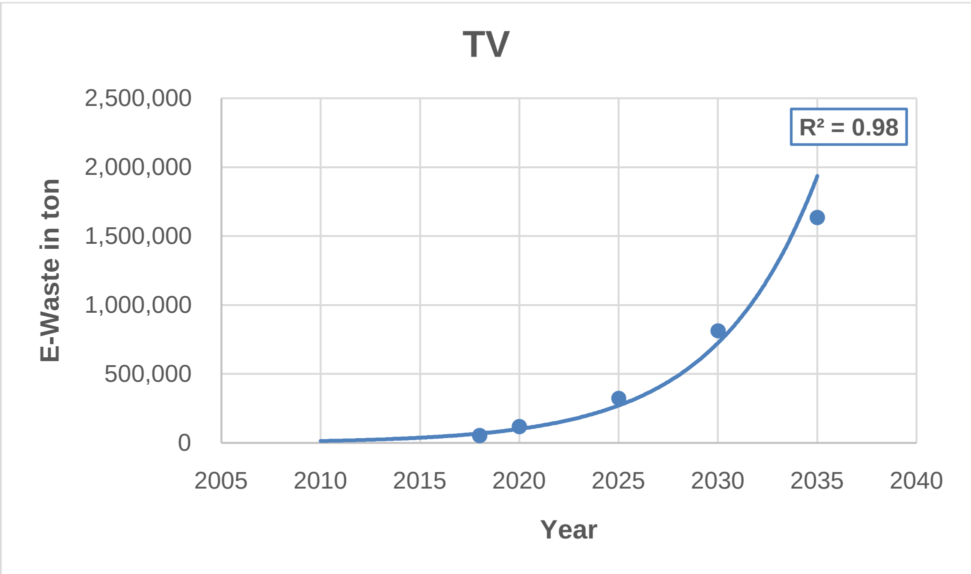


Figure 4.16: E-waste Generation (Fan) in Ton per Year

The total e-wastes from these eight items has been summed up and is presented in Figure 4.17. It has been found from this figure that growth rate of e-waste generation is around 20% per year and it will reach upto 4.62 million ton by year 2035.

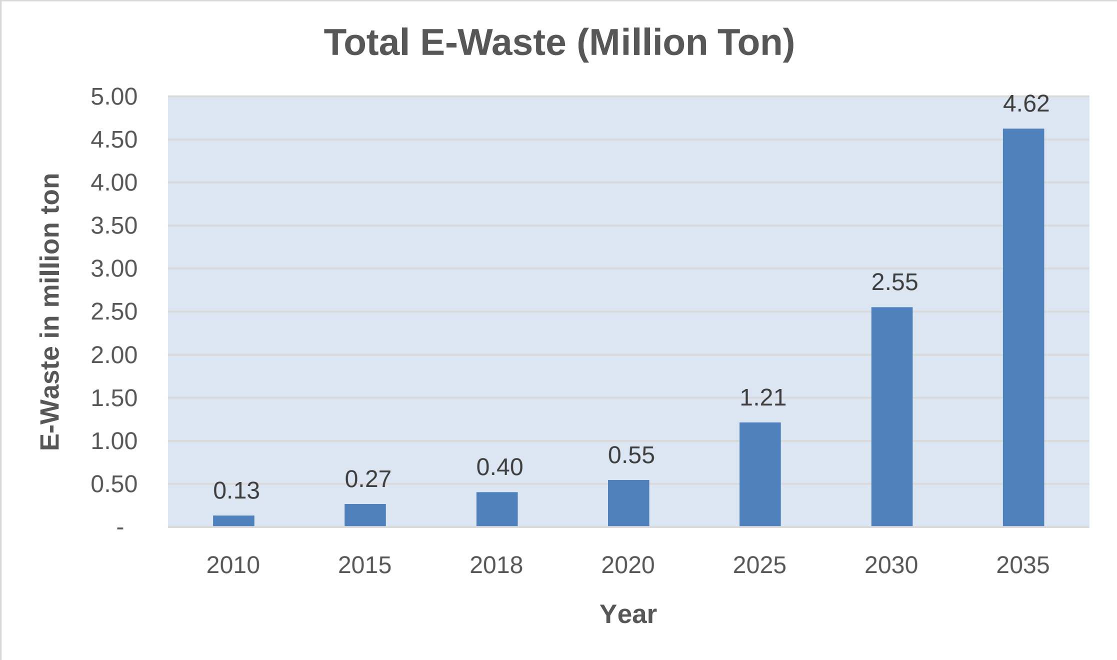


Figure 4.17:Estimated amount of E-Wastesin Bangladesh up to Year 2035

4.3 ESTIMATION OF E-WASTE AMOUNT FROM PRIMARY DATA

The present study has also undertaken an attempt to estimate the amount of e-wastes of Bangladesh by collecting primary data from e-waste generators, collectors, recyclers and exporters. With this objective, questionnaire and field survey were conducted among the e-waste collectors, e-waste dealers and bhangari shop owners. It has been known from DoE source that there are nine of enlisted recycler and exporter who are involved with recycling and exporting of e-wastes. Among the nine listed recyclers, data has been collected from only three recyclers, others could not be contacted. An approximate estimation of e-waste generation in the educational institute has also been made in the present study.

4.3.1 E-Wastes Data from Questionnaire and Field Survey

Primary data of generated e-wastes was also collected by questionnaire and field survey conducted among the e-waste collectors, dealers, Bhangari shop owners, recyclers and exporters. The field survey locations are Elephant Road, Nimtoli, Motijheel and Chankhar Pool. Among the four locations, total 65 questionnaire survey was conducted among which 21 are with e-waste collectors who collects e-waste from households and different locations and sell them to bhnagari shops, recyclers, e-waste dealers. The rest (44) are with e-waste dealers, bhangari shop owners etc. It has been found from the survey that a good number of shops exists in these four locations who collects, repair, recycle, sell and finally dispose of the e-wastes(Table 4.2).

Table 4.2: Number of Shops in Survey areas dealing with WEEE

Type of Shop	Elephant Road	Chankhar Pool	Nimtali	Motijheel
Computer Repairing & Used Computer Collector Shops	90-100	--	--	--
Bhangari Shops	8-10	60-70	70-80	35-40
Refrigerator& AC Repairing Shops	--	20-25	--	--
Photocopier Repairing & Collector Shops	--	--	--	40-50

Photo 4.1(a):Conducting Questionnaire Survey

Photo 4.1(b):E-waste Collector Shop

Photo 4.2 (a): Sorting of E-waste

Photo 4.2 (b): E-waste Recycling Shop

Photo 4.2 (c): Bhangari Shop

Photo 4.2 (d): Information Collection by Surveyor

Photo 4.2 (e):Bhangari Shop

It has been found from the survey that at Elephant road, mainly used/obsolete computer and mobile phones and their accessories are collected, repaired, recycled and sold to the third party. Nimtoli and Chankharpool shops deal with mainly discarded AC, TV, Freezer, Computers, Cables, Fans, Toaster, Microwave ovens etc. and Motijheel shops deal with Photocopiers, Scanners, Printers etc. items.The data collected from this filed survey is summarized and presented in Table 4.3.

Table 4.3: Amount of E-Wastes collected by E-waste Collectors

Location	Items	E-Waste Amount (kg/month)	
		Range (kg/month)	Average (kg/month)
Elephant Road (Sample size: 7)	Computer and its accessories, Mobile phones, PCB of Computers and mobile phones, CRT Monitor, Sim Cards and others	45 – 1000	389
Chankharpool (Sample size: 8)	Computers, PCB of Computers and mobile phones, Refrigerator, TV, Microwave oven, AC, Electric Fan, Sim cards etc	60 - 2450	814
Motijheel (Sample Size: 8)	Printer, Photocopiers, PCBs, Scanners etc.	100 - 580	346

Table 4.4: Amount of E-Wastes in Bhangari shops, Dealers in Survey locations

Locations	Amount (kg/month)	
	Range (kg/month)	Average (kg/month)
Nimtoli (Sample size 21)	150 - 2520	975
Chankharpool (Sample size: 13)	470 - 4210	1986
Motijheel (Sample size: 8)	660 - 7500	2966

The survey findings show that there are number of Bhangari shops in those stated locations (Table 4.4). An approximate amount of e-waste has been calculated from this average amount multiplied by the number of shops and is presented in Table 4.5.

Table 4.5: Total amount of E-Wastes in studied locations

Locations	Average No. of Shops	Average Amount of E-wastes kg/month	Amount of E-Wastes (kg/month)	Total Amount (kg/month)	Total Amount (kg/year)
Elephant Road	100	389	38900	518115	6217380 (= 0.0062 Million Ton/year)
Chankharpool	85	1986	168810		
Nimtoli	75	975	73125		
Motijheel	80	2966	237280		

E-waste data was also collected from visiting some recycling business entities and exporters. Two Ship Recycling Industries were also visited to see how they handle their wastes, mainly e-wastes from ships and collect the data.

4.3.2 E-Waste Data fromRecycling Industries

Data from Recycler 1

The present research team visited to the factory site ofRecycling Industry 1 on April 12, 2018. This recycling business was established in 2006 and it started exporting of PCBs since 2008. Their capacity of processing PCB is 100 Ton/month and exporting is 30-50 Ton high grade PCB/month.The activities involved in their recycling process is shown in Figure 4.18 and Photos 4.3, 4.4, 4.5 and 4.6. The collected e-wastes amount for processing and exporting by this recycler is shown in Table 4.6.

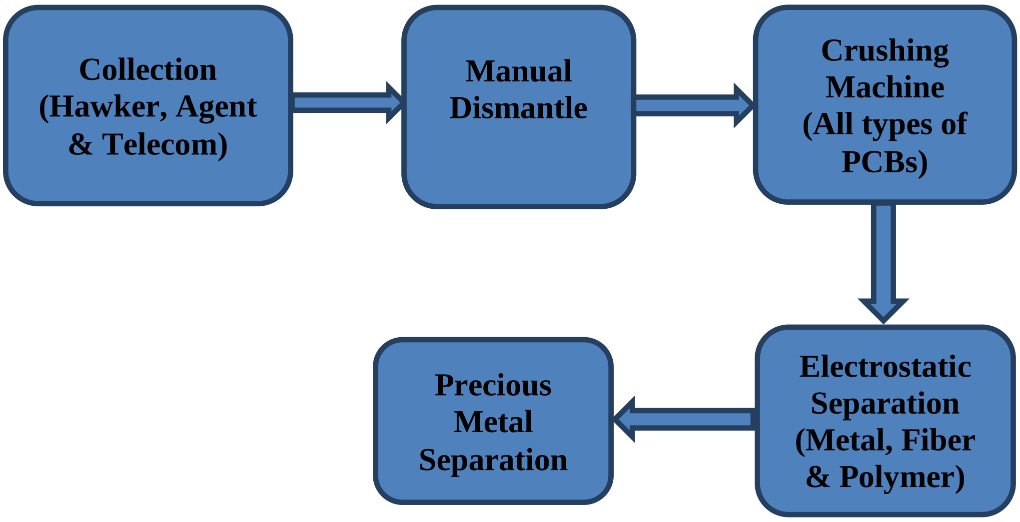


Figure 4.18: Flow diagram of Recycler-1

The key activities and other information gathered from the field visit are summarizedbelow:

- Monthly Processing: PCBs: 100 tons, Cable: 50 ton
- Machine capacity: 4-5 ton per day
- Export: 30-50 tons high grade PCBs
- Value Metal Recovery: Recycle 17 types of metal like Gold, Copper, Silver, Palladium etc. Recycled metal is 30% of PCB weight, of that Copper- 80%. Gold- 1%.
- Cable Recycling: Recover metals from zero (Teflon) cable. 30-40% copper is recovered from foreign cables. From local cable the percentage is 5-10%. The remaining is plastic.
- Active parts from waste equipment are resold or exported.
- Stocking recyclable wastes for
- Most of the infrastructures (stairs etc.) are made of server casing
- Recycled polymer and fiber are used to make composite board that can be used in different applications like washroom door.

Future Prospects:

- Chemical lab for recovery of value metals more efficiently in 5th floor of plant area. It'll start within 6-10 months.

Causes for Concern

- No interaction with Department of Environment
- No proper dumping or recovery of hazardous metals
- Still no battery processing
- Workers are exposed to stocked e-waste.

Photo 4.3 (a): Metals after Dismantling Process

Photo 4.3 (b): Fiber Separation from Wire

Photo 4.4 (a): Cellphone Casings

Photo 4.4 (b): Control Unit of Crusher and Electrostatic Precipitator

Photo 4.4 (c): Copper Motors Used in Hard discs

Photo 4.4 (d):Server Circuit Boards

Photo 4.5 (a): Manual separation of Copper Wires

Photo 4.5 (b): Hydraulic Press for Compaction

Photo 4.5 (c):Rare Earth Magnets Used in Hard discs

Photo 4.5 (d): Powder Products after Processing

Photo 4.6 (a):Coil Wire

Photo 4.6 (b):Telecom Casing

Table 4.6: Data collected from Recycler 1

	2013	2014	2015	2016	2017	2018	Total E-waste (kg)	Avg. E-waste (kg)
Amount of E-waste Collection (kg)	3434674	-	257923	166880	165475	215669	5729896	1145979
Amount of E-waste Export (kg)	647912	113213	90509	17509	108922	-	978066	195613

Data from Recycling Industry 2

A visit was paid by the research team to Recycling Industry 2 on June 30, 2018 (Photo 4.7). This factory is located near Hemayetpur Bus Stand, Savar, Dhaka. The company mainly sources electronic waste materials from telecom industries as well as from Police, Banks etc. According to their senior management, they collect 700 metric ton of e-wastes on average from telecom companies, of which 3-5% consist of printed circuit boards (PCB). In the 2016-2017 time period, they collected 300 – 400 metric ton of e-wastes from telecom companies and 50 tons of communication devices from Bangladesh Police. In 2015-2016, they collected 600 metric ton of waste metallic products and 100 metric ton waste PCB.

The operating challenges faced by this company are not unlike those of other e-waste recycling companies. They echoed the same complains that the absence of a systematic, transparent, centralized collection system of e-waste is the most dominant factor in their high cost of business. Most of the used consumer electronics do not reach licensed e-waste recyclers; they are lost to the informal e-waste recycling center, where there is little or no compliance with employee's health and environmental safety regulations. These waste electronics, which are lost from the formal waste stream, are either incinerated or deposited in landfills. Incineration gives off toxic gases, while landfills reduce the soil fertility and leach into nearby water bodies, thus destroying local aquatic fauna and poisoning the water supply of communities. Since most of the consumer waste electronics do not reach to them, they rely on their business contracts with telecom companies and other government/NGO institutions for a steady supply of value-metal enriched e-waste components.

The company management predicts that since the telecom sector has grown mature and thus ceased expansion, telecom companies will soon become a minor source of e-wastes and waste consumer electronics will occupy the majority share. Regardless, the company predicts that with the anticipated arrival of 5G network technology in 2 - 3 years, all existent telco hardware will become obsolete and generate approximately 20,000 - 50,000 metric ton of e-wastes in the near future. The collected e-wastes and some of the activities of this industry is shown in Photo 4.8 to 4.10.

Photo 4.7:Visit to the Recycling Industry 2

Photo 4.8 (a): Manual Dismantling Process

Photo 4.8 (b): Samples of Different Type of E-wastes

Photo 4.9 (a): Discarded sim cards with gold plated chips

Photo 4.9 (b): Segregated Gold Plated Connector Components

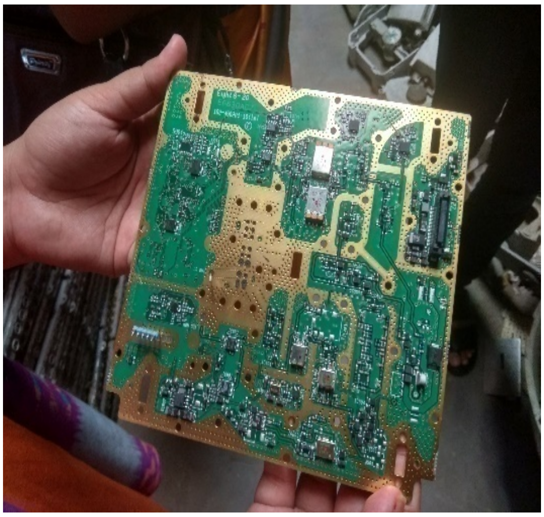


Photo 4.9 (c): Spare PCBs

Photo 4.9 (d): Cast Iron Components Sent to Army Facilities for Casting

Photo 4.10 (a): BTS Component Card

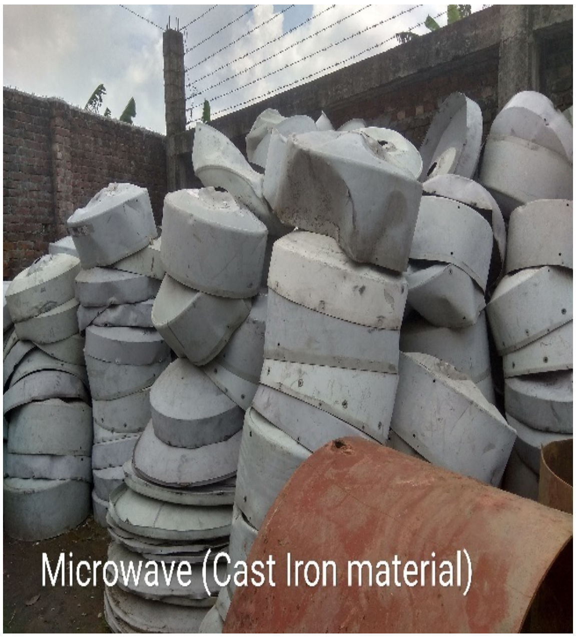


Photo 4.10 (b): Microwave (Cast Iron Material)

Photo 4.10 (c): Telco Tower Rectifier

Photo 4.10 (d): Telecom Server Metallic Casings

The images above show the discarded telecom and related miscellaneous electronic equipment. It is evident that telecom companies contribute the lion's share of all their sourced commodities. The images above show the value-added final product that are obtained by dismantling high gold content PCB of telecom equipment. These are exported to e-waste processing companies in Singapore, Taiwan, China, Japan and other countries where value metals are chemically extracted from these segregated components. Thus, the labor-intensive mechanical processing step of the metal recovery stream is completed in developing countries like Bangladesh where cheap labor is a big advantage.

4.3.3 E-Waste Data from Ship Recycling Industries

A visit has been made to two Ship Recycling Industries, Sitakundu, Chottogram on June 7, 2018 (Photo 4.11). One compliant ship recycling industry and one non-compliant industry were visited.

Photo 4.11(a):Visit of Ship Breaking Industry

Photo 4.11 (b):Different Types of E-wastes

Photo 4.11 (c):E-Wastes Store room

Photo 4.11 (d):Electric Cables

Ship recycling industry gets different type of electrical and electronic equipment which are normally found in a ship. Such items are lighting equipment, TV, Freezer, Air conditioner, control panel, smoke detector, cables, microwaves, toasters, irons, fans, heaters, washing machine, cooking stoves, electric kettle, etc. The amount of EEE varies depending on type and capacity of ships. According to the management of this industry, for a 40,000 Ton ship contains average 25-30 Ton of e-waste, whereas 15,000-20,000 Ton ship contains average 15-20 Ton of e-wastes. Usually 200-300 kg of lighting equipment and 8-10 Ton of cables are collected from each ship after dismantling.After breaking and dismantling the ship, they normally tender out the EEE for selling.

It has been found from DoE, Chattogram Office and other literatures, that average 200 ships are dismantled in Ship Breaking Yard in Bangladesh each year of which includes Oil Tanker, Bulk Carrier, General Cargo, Chemical Tanker, Dumb Barge, TUG Boat, LPG Tanker, Container ship, Vehicles carrier, Fish carrier, RefrigeratedCargo, Crane Barge, Drilling Tender Barge, Seismic Research Vessel etc.Considering approximately 200 ships are dismantled each year in Bangladesh and EEE item are collected on average 20 Ton/ship, then yearly amount of total e-wastes from ship yard is around 4000 Ton.

4.3.4 E-Wastes Amount in an Educational Institute

To estimate the generated amount of e-waste in an educational institute, Bangladesh University of Engineering and Technology (BUET) has been considered a sample institute and questionnaire and field survey was conducted in eleven academic departments and four offices including Controller of Examinations Office, DSW Office, Medical Centre and Registrar Office of BUET to estimate its e-wastes in a year. It has been found from the survey that most of the e-waste items are computers, printers, photocopiers, scanners, multi media projectors etc. and the total amount of e-wastes is around 5.4 ton/year.University authority floats tender to sell the stored e-wastes to the recycler and thus they manage their e-wastes. According to UGC website (www.ugc.gov.bd), the number of public universities in Bangladesh is 41. Although these universities vary in sizes, types and number of faculties, for ease of estimation it is considered that average e-waste generation per university is 5.4 Ton/year, therefore the total number of e-waste from these 41 universities is 220 Ton/yr. It is noted here that the e-waste in private universities has not been considered in the study.

4.3.5 Total Amount of E-wastes from Above Sources

The data obtained from questionnaire survey, from recyclers, exporters and ship recycling industries, institutions are compiled and presented in Table 4.7.

Table 4.7: Total Amount of E-wastes in Recycling Sector

Source	Ship Recycling Industry	E-Waste Recycling Industry 1	E-Waste Recycling Industry 2	Bhangari Shops/Dealers	E-Waste Exporter	Universities, Institutional Organizations
Average Amount of E-Waste (Ton/year)	4000	1146	700	6217	1000	220
Total	13283 Ton/year (= 0.0133 Million Ton/year)					

Table 4.7 shows the total amount of e-wastes (0.0133 million ton/yr) that enter into the recycling and exporting businesses in Bangladesh. This amount is around 3% of the total estimated amount of estimated e-wastes obtained by mathematical model based on sales data (0.40 million ton in year 2018) which is a very insignificant percentage and indicates that almost 97% of generated e-wastes go to the landfill. It is worthy to mention here that this data only covers a small recycling area of Dhaka city and a few recycling businesses, not the whole country and therefore, it did not represent the actual scenario on recycling amount of e-wastes for entire Bangladesh.

4.4 EVALUATION OF GENERATED E-WASTES FROM PREVIOUS STUDIES

It has been found from the review of existing data that mobile phone, computers, TV, Freezer, Air Conditioners, CFL bulbs are the major contributors in e-wastes (ESDO, 2014; RE-TEM 2015). The present study found that the contribution of IT Server in e-waste stream is increasing day by day as the Telecommunication service is fast changing from one generation to another such as from 3G to 4G and then to 5G within a short span of time in near future. There are other sources of e-wastes such as washing machine, medical and dental equipment, microwaves oven and so many but their contribution is not significant and data on them are not also available. Table 4.8 shows a comparison of available data on the major items of e-wastes cited in different previous studies.

Table 4.8: Amount of E-Wastes in Previous Studies

Studies	Mobile Phones	Computers	Television	Air Conditioner	Freezer	CFL Bulbs	Medical and Dental Equipment Waste	Ship Breaking Yard	Total E-Waste Amount)
ESDO, 2014 (Million Ton)	0.0211	0.0307	0.86	-	-	0.0032 Million Ton	0.0395 MT	8.86 MT	9.81 Million Ton (0.94 MT excluding Ship breaking yard's e-wastes)
Re-Tem, 2015 (For DSMA, in piece)	1320000 (0.000152 MT)	96000 (0.00012 MT)	64765 (0.00188 MT)	18000 (0.00095 MT)	27000 (0.0033 MT)	5,300,000 pieces (0.00035MT)	-	-	0.007 MT
Reza & Yusuf, 2012;	0.0077 MT	0.01796 MT	-	-	-	-	-	-	0.0256 MT
Choudhury, 2014	-	-	-	-	-	-	-	-	0.004 MT (309105 kg/month)
Balde et al., 2017	-	-	-	-	-	-	-	-	0.142 MT

(Note: For the sake of comparison, amount of E-wastes from Re-Tem's study was obtained by converting their data into million ton using the conversion factor stated in Table 4.1).

It has been found from Table 4.8 that the amount stated in different studies varies within a wide range for each item. It is noted that ESDO (2016) has considered more itemsin their study than Re-Tem, (2015) and Re-Tem's study area covered only Dhaka Statistical Metropolitan Area (DSMA) while ESDO's (2016) study included Dhaka City and Chittagong. The other studies only reported e-wastes amount from mobile phones and computers and the detail information on their study area and method could not be found. Regarding ESDO findings, the major share is from ship breaking yard (8.86 MT) and excluding this amount, the total amount of e waste is 0.955 MT whereas Re-Tem's amount for DSMA is 0.007 MT. The Global E-Waste Monitor (2017) reported that the amount of generated e-waste in Bangladesh in 2016 is 0.142 MT (Balde et al., 2017). Therefore, it has been observed from the previous study findings that it is very difficult to come up to a reasonable amount of e-waste generation in Bangladesh. While evaluating the previous findings (ESDO and Re-Tem), the present research observed that the considered growth rate of different items in each study varied in a wide range in those studies. As for example, for CFL bulb, ESDO considered a uniform growth rate of 29% whereas, Re-Tem considered a decreasing growth rate (15% to 2%) which seems more logical since use of CFL is decreasing now-a-days because of increased use of LED bulbs. Another striking finding of ESDO (2016) is the amount of e-wastes from Ship Breaking Industries (8.8 MT). In their study, they came to this figure considering that average 200 ships/year illegally contain 500 containers each fully loaded with 1200 computers (ESDO, 2014) which seems a bit exaggerated figure. It is very difficult to prove that the ships coming for breaking to Bangladesh seashore bring illegal computers and even if they do so, not all 200 ships come fully loaded with illegal computers. It should also be noted here that total amount of e-wastes generated in 2016 is 18.7 MT in Asia including 7.2 MT in China and 1.98 MT in India (Balde et al., 2017). Therefore, comparing these figures with ESDO's finding, the e-waste amount in Bangladesh found by ESDO seems to be very high and unrealistic. If we exclude the amount from ship breaking yard, then total amount is 0.955 MT which seems logical compared with the amounts of India.

Chapter 5
Assessment of Impacts of E-Wastes

5.1 INTRODUCTION

Inappropriate recycling of e-waste generates significant hazardous emissions, with severe impacts on health and environment (Chapter 2, Section 2.4). Health and safety risk associated with informal recycling include occupational health risks posed to e-waste collectors and handlers and community health risks posed to the surrounding community. These risks can originate from the nature of the wastes or the process of collecting, dismantling, processing, recycling and disposing of it. In this context, three levels of toxic discharge can be identified: i) Primary emission: hazardous substances that are contained in e-waste (i.e lead, mercury, arsenic, Poly Chlorinated Biphenyl etc.) ii) Secondary emissions: hazardous reaction products of e-wastes as a result of improper treatment (e.g. dioxins or furans formed by open burring or inappropriate smelting of plastics with halogenated flame retardants and iii) Tertiary emissions: hazardous substances or reagents that are released into environment (e.g. cyanide or other leaching agents, mercury for gold amalgamation) because of inappropriate handling and treatment. In Bangladesh, e-wastes handling, dismantling and recycling are carried out in a very crude manner in informal sector; no safety measures are adopted in doing these activities. Therefore, the workers are directly exposed to the risk of health hazards and the people are indirectly exposed to the risk of environmental (air, water, soil) pollution due to improper management and disposal of e-wastes. The present research aims to study the impacts of the inappropriate handling of e-wastes on human health and environment and this chapter shows a detail assessment of the risk from the toxic hazardous elements in the e-wastes due to the improper handling, processing, recycling and disposal.

5.2 ASSESSMENT OF IMPACTSON HUMAN HEALTH

Occupational and direct local exposure is the most evident scenario for the people associated with the e-waste collection and recycling process. To assess the impacts, twoapproaches were adopted in this study. First attempt has been made to assess the impacts of e-wastesby conducting direct survey. The second approach is an indirect one. In the secondapproach, a risk analysis is carried out to determine if the exposed workers are at risk or not by handling the e-wastes. The risk assessment is conducted using the USEPA Guidelines values.

5.2.1 Survey Findings

In direct method, questionnaire survey was conducted among the people who are involved in collection, dismantling, separation, processing and recycling of e-wastesto know about the health effects of e-wastes (Photos 5.1, 5.2 and 5.3). The total sample size is 65 and study locations are Elephant Road, Chankharpool, Motijheel and Nimtoli.

Photo 5.1 (a):Dismantling the Parts from PCB

Photo 5.1 (b): E-waste Recycling Shop

Photo 5.1 (c):Fibre Separation from the Wire

Photo 5.1 (d):E-waste Stored in Open Road Side Area

It has been found from the survey that none of those people are aware of the hazards and health risks associated withimproper handling and recycling of e-wastes.Survey findings revealed that only 7% people knew that e-wastes contain toxic chemicals, 24% reported dust emission, specially from processing of scanner, printer and photocopier, 9% knew about acid contains in battery, and 3% knew that refrigerator contains toxic gas. 10 people out of 65 reported that they have experienced injuries (cut in hands, legs and hurt at head) while handling, dismantling andrecycling of e-wastes. During the survey period, only one person was seen wearing a face musk (Photo 5.2 (a))while dismantling a fridge. A fewworkers complained about cold and other minor health related problems and they were not sure about the cause of these problems.

Photo 5.2 (a): Worker with a Face Musk while Dismantling a Fridge.

Photo 5.2 (b):Dismantling Process of Photocopier Machine

Photo 5.2 (c): An Injured Worker During the Dismantling Process

Photo 5.2 (d):Separating the Parts from the Digital Banner Printer

Photo 5.3 (a): E-wastes Kept in Open Place **Photo 5.3 (b): Bhangari Shop**

Photo 5.3 (c): E-waste (PCB boards)

It has been observed from the field survey that most of the workers involved in e-wastes recycling works are in their teens (average age 18 years). They work bare handed, bare footed, without any safety gears. The dermal contact of toxic chemicals poses a risk to their health. Again, continuous exposures (8-12 hours daily) to e-wastes and inhalation of toxic gases from different activities in the workplace make them vulnerable to different diseases. Most of the times, e-wastes are kept in open air(Photo 5.1 (d)&5.3(a))and there exists a good chance of leaching and emission of toxic chemicals by rain and wind and easily get into the environment. The workplace injury is very common in handling, dismantling and recycling of e-wastes(Photo 5.2: (c)). In fact, one of the members of the survey team has experienced a drill machine injury in one Bhangari shop while conducting the survey. It is evident that during the dismantling process and incident of injuries, workers come in directcontact of the hazardous elements in e -wastes and are exposed to the risk posed by those hazardous elements, although they are neither aware of it, nor they do care about it.

5.2.2 Analysis of Risk

A risk analysis has been carried out for the workers who are involved in handling and recycling since e-wastes contain many toxic and hazardous elements (i.ePb, Cr, Cd, As, Be, Hg etc.) which may affect their health severely. Risk assessment is a tool for understanding the health and environmental hazards associated with harmful wastes. According to the definition, a risk is a function of hazard and exposure.Risk assessment includes following essential elements: hazard identification, dose-response assessment, hazard or risk exposure assessment and risk characterization.

Hazard Identification

Hazard identification refers to the identification of type and nature of adverse effects that an agent/substance has a capacity to cause in an organism, system or (sub) population. It is the first stage of risk assessment. Risk assessment is normally done on the potential risk of chemicals to cause cancer. Chemicals may be categorised as carcinogens which are found to cause cancer and non-carcinogenic chemicals are those that do not cause cancer.

Toxicity and Exposure Assessment

Dose-Intake Rate, I:

The Dose-Intake Rate means the amount of contaminant hazards materials per unit body weight per day is taken by the exposure or human being.

The Dose-Intake Rate procedure has been used to calculate permissible chronic exposure levels for humans based on non-carcinogenic or carcinogenic effects. The Acceptable Daily Intake (ADI) is the amount of a chemical to which a person can be exposed each day for a long time (usually lifetime) without suffering harmful effects.

The intake rate (I) is sometimes denoted as CDI, which stands for the Chronic Daily Intake

The Intake Rate, I (in mg of contaminant per kg of body weight and per day) is calculated as follows: (Nazaroff, Alvarez-Cohen, 2001)

$$\mathrm{I} = A \times C \times \frac{\mathrm{CR} \times \mathrm{EF} \times \mathrm{ED}}{BW \times AT}$$

Where,

C = average concentration of contaminant at exposure

(in mg/L if in water, or mg/mg if in soil, or mg/m^3 if in air)

CR = contact rate (in L/day, mg/day or m^3/day)

EF = exposure frequency (in days per year)

ED = exposure duration (in years)

BW = body weight (in kg)

AT = period over which exposure is averaged (in days)

A= Absorption Percentage

For carcinogenic substances, the risk is then evaluated as the individual excess lifetime cancer risk (IELCR) or Risk Factor R:

IELCR(R)= I×SF

Where,

I = Intake Rate for Carcinogenic

SF = Slope Factor

If IELCR(R) is > 10^{-6} , then risk is unacceptable (Nazaroff-Cohen, 2001).

Cancer Slope Factor (SF):

Cancer slope factors (CSF) are used to estimate the risk of cancer associated with exposure to a carcinogenic or potentially carcinogenic substance. A slope factor is an upper bound, approximating a 95% confidence limit, on the increased cancer risk from a lifetime exposure to an agent by ingestion or inhalation. (Wikipedia, 2018). The CSF is also called a "potency factor" and is used to calculate the Incremental Lifetime Cancer Risk by multiplying the CSF by the chronic daily intake (CDI). The CDI is the dose over a lifetime and is expressed in mg/kg-day. (IRIS-USEPA Guideline, 2018).

Risk for Non-carcinogenic Substances

Non-carcinogenic substances are characterized by a threshold below which the body is able to cope with or recover from the exposure. A brief or low exposure leaves no consequence until the next exposure. Carcinogenic substances are different as they have no such threshold. All repeated exposures to a carcinogenic substance add up, and the risk is never zero. At low doses, the risk is proportional to the exposure (IRIS- USEPA Guideline, 2018). For non-carcinogenic substances, the risk is determined as the Hazard Quotient *HQ*:

$$HQ = \frac{I}{RfD}$$

Where,

I = Intake rate for Non-carcinogenic

RfD = Reference Dose factor

The *RfD*is the ratio of the No-Observable Adverse Effect Level (NOAEL) over the Uncertainty Factor (UF).

$$RfD = NOAEL / UF$$

Where,

RfD = Reference Dose Factor

UF = Uncertainty Factor

NOAEL = No-Observable Adverse Effect Level

Hazard Quotient (HQ)is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. If the Hazard Quotient is calculated to be less than 1, then no adverse health effects are expected as a result of exposure. If the Hazard Quotient is greater than 1, then adverse health effects are possible.

Therefore,

$HQ < 1$; Safe

$HQ > 1$; Unsafe

Reference dose factor and slope factor for different substances are shown in Table 5.1.

Table 5.1: Reference Dose Factors and Slope Factors for Different Substances (Nazaroff and Alvarez-Cohen, 2001)

Estimated Reference Dose Factors (*RfD*) and Slope Factors (*SF*)

(Nazaroff & Alvarez-Cohen, Table 8.E.5 page 572)

Substance	Oral *RfD* mg/(kg.day)	Oral *SF* $[mg/(kg.day)]^{-1}$	Inhalation *SF* $[mg/(kg.day)]^{-1}$
Arsenic	3.0×10^{-4}	1.5	50
Benzene	4.0×10^{-3}	2.9×10^{-2}	1.5×10^{-2}
Benzo(*a*)pyrene	(no data)	7.3	6.1
Cadmium	5.0×10^{-4}	(no data)	6.1
Chlordane	5.0×10^{-4}	0.35	0.35
Chloroform	0.010	6.1×10^{-3}	8.1×10^{-2}
Chromium VI	0.003	(no data)	41
1,1-Dichloroethylene	0.05	0.58	1.16
Methyl mercury	1.0×10^{-4}	(no data)	(no data)
Naphthalene	0.02	(no data)	(no data)
PCBs	(no data)	7.7	(no data)
Dioxin	(no data)	$1.5 \times 10^{+5}$	$1.5 \times 10^{+5}$
TCE	5×10^{-4}	0.046	0.002
Toluene	0.08	(no data)	(no data)
Vinyl chloride (VC)	0.003	1.4	0.295

For additional values, consult: http://cfpub.epa.gov/ncea/iris/compare.cfm

The USEPA default values for use in exposure assessment calculation known as Maximally Exposed Individual" (MEI) is shown in Table 5.2.

Table 5.2: MEI Chart (USEPA Guideline Values, 1989)

Parameter	Worker
Contact Rate (CR)	a) 1L/day drinking water b) 50 mg/day soil and dust ingestion c) 30 m^3/day inhalation
Exposure Frequency (EF)	300 days/year
Exposure Duration (ED)	Actual event duration or 25 years if chronic
Body Weight (BW)	55 kg
Period over which exposure is averaged (AT)	a) Actual event duration if not carcinogenic, b) 365 days/year ×70 years if carcinogenic

For non-carcinogenic substances, AT = ED (assumed), For carcinogenic substances, AT = Life Time (assumed)

Health Risk Assessment on Workers

It is already known from literatures (Chapter 2) that e-wastes contain various toxic heavy metals such as lead, cadmium, mercury, chromium etc. which are very harmful for human health. The present study has analysed PCB of cell phones and found significant amount of heavy metals in them (Chapter 6). Some of the heavy metals found in this analysis are shown in Table 5.3.

Table 5.3: Characterization of Cell Phones PCB (treated by Aqua-regia)

Parameters	Concentration Range (mg/l)
Cadmium (Cd)	< 0.01 - 0.18
Chromium (Cr)	6.5 – 278
Cobalt (Co)	9.04 – 32.5
Lead (Pb)	44 – 1270
Mercury (Hg)	< 0.01 – 6.29

When the workers dismantle those items, their health are at risk by those elements through ingestion and inhalation. To assess the risk of the people associated with e-wastes handling and recycling, workers are classified in three age groups: i) W-A: workers below 15 years of age ii) W-B: Workers between 15-25 years of age and iii) W-C: Workers above 25 years of age. It is assumed that they are exposed to e-wastes around 10 hours per day and the exposure time is considered 300 days in a year. The body wt. and avg. height of these workers are taken from the Table 5.4. Detail information of the workers considered in this analysis is shown in Table 5.5.

Table 5.4: Health Fitness Weight Chart for Men and Women (WHO Global Database, viewed inhttp://www.who.int/nutrition/databases/bmi/en/)

Health Fitness Weight Chart for men and wemen

Ideal Weight Chart for Women		Ideal Weight Chart for Men	
Height	Weight	Height	Weight
4ft. 8in.	6st.11 lb. - 8st.	5ft. 1 in.	8 st. 4 lb - 9 st. 8 lb.
4ft. 9in.	7st.- 8st. 2 lb.	5ft. 2 in.	8 st. 7 lb - 9 st. 11 lb.
4ft. 10in	7st. 2 lb. - 8st. 5 lb.	5ft. 3 in.	8 st. 10 lb. - 10 st.
4ft.11in.	7st. 5 lb. - 8st. 8 lb.	5ft. 4 in.	8 st. 13 lb. - 10 st. 4 lb.
5ft.	7st. 8 lb. - 8st. 11 lb.	5ft. 5 in.	9 st. 3 lb. - 10 st. 7 lb.
5ft. 1in.	7st. 11lb.- 9 st.	5ft. 6 in.	9 st. 7 lb. - 10 st. 12 lb.
5ft. 2in.	8st.- 9 st. 4 lb.	5ft. 7in.	9 st. 11 lb. - 11 st. 3 lb.
5ft. 3rd.	8st. 3 lb.- 9 st. 8 lb.	5ft. 8 in.	10 st. 1 lb. - 11 st. 7 lb.
5ft. 4in.	8st. 7lb. - 9 st. 12 lb.	5ft. 9 in.	10 st. 5 lb. - 11 st. 11 lb.
5ft. 5in	8st. 7 lb. - 10 st. 2 lb.	5ft. 10 in.	10 st. 9 lb.-12 st. 1 lb.
5ft. 6in.	9st. 1lb. - 10 st. 6 lb.	5ft. 11 in.	10 st. 13 lb. - 12 st. 6 lb.
5ft. 7in.	9st. 5 lb. - 10 st. 10 lb.	6ft.	11 st. 8 lb. - 13 st. 3 lb.
5ft. 8in.	9st. 9 lb. - 11st.	6ft. 1 in.	11 st. 12 lb. - 13 st. 7 lb.
5ft. 9in.	9st. 13 lb. - 11st. 5 lb.	6ft. 2 in.	12 st. 2 lb. - 13 st. 11 lb.
5ft. 10in.	10st. 3 lb. - 11st. 10 lb.		

Table 5.5: General Information of Exposed Workers

Exposed Group	Type of Case	Years range	Avg. Height (BBS,2011)	Avg. Body Weight (kg)	Avg. Exposure Duration (hours/day)	Exposure Frequency (days/year)
Worker	W-A	Below 15 years old	4’-6”	25	10	300
	W-B	15-25 years old	5’-1”	50	10	300
	W-C	Above 25 years old	5’-4”	60	10	300

The risk assessment has been carried out among the workers for the elements lead, cadmium and chromium. Although the data shows the presence of a considerable amount of Pb, Cd and Cr in PCB (Table 5.3),it could not be ascertained that the workers inhale or ingest that concentration directly. Therefore, for the sake of assessmentby inhaling (through air), the concentration of Pb, Cd and Cr has been assumed as the concentration found in the air (Islam et al., 2015). The carcinogenic risk factor on the workers due to Cd, Cr and Pb are shown in Tables 5.6, 5.7 respectively. A sample calculation for this analysis is also presented in Annex C. It is observed from the Tables 5.6 to 5.8, that the health of all the three types of age group workers are at carcinogenic risk through inhalation of toxic Pb, Cd and Cr.

Table 5.6: Carcinogenic Risk Factor (Chromium)

Concentration of Cr: 9.08 ng/m^3 (Islam et al., 2015)

Medium: Air

Formula: Intake Rate, I = A × (C×CR×EF×ED)/(BW×AT)

Risk Factor, R = I ×SF

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (m^3/day)	Concentration, C (mg/m^3)	Absorption Percentage, A	Intake rate, I (mg/kg.day)	Inhalation Slope Factor $(mg/kg.day)^{-1}$ (Table 5.1)	Risk factor	Comments
W-A	35	10	300	365	30	$9.08×10^{-6}$	50	$3.20×10^{-6}$	41	$1.31×10^{-4}$	Unacceptable
W-B	50	10	300	365	30	$9.08×10^{-6}$	50	$2.24×10^{-6}$	41	$9.18×10^{-5}$	Unacceptable
W-C	60	10	300	365	30	$9.08×10^{-6}$	50	$1.87×10^{-6}$	41	$7.67×10^{-5}$	Unacceptable

Table 5.7: Carcinogenic Risk Factor (Lead)

Concentration of Pb: 305.6 ng/m^3 (Islam et al., 2015)

Medium: Air

Formula: Intake Rate, I = A × (C×CR×EF×ED)/(BW×AT)

Risk Factor, R = I ×SF

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (m^3/day)	Concentration, C (mg/m^3)	Absorption (%), A	Intake rate, I (mg/kg.day)	Inhalation Slope Factor, SF (https://oehha.ca.gov/chemicals/lead-and-lead-compounds) $(mg/kg.day)^{-1}$	Risk factor (R)	Comments
W-A	35	10	300	365	30	305.6×10^{-6}	50	1.07×10^{-4}	4.2×10^{-2}	4.50×10^{-6}	Unacceptable
W-B	50	10	300	365	30	305.6×10^{-6}	50	7.54×10^{-5}	4.2×10^{-2}	3.17×10^{-6}	Unacceptable
W-C	60	10	300	365	30	305.6×10^{-6}	50	6.28×10^{-5}	4.2×10^{-2}	2.64×10^{-6}	Unacceptable

The risk analysis due to these elements (Pb, Cd, Cr)through ingestion are also carried out and presented in Tables5.6 to 5.7 and sample calculation is shown in Annex C. It is noted here that since the concentration of Pb, Cd and Cr in water/food etc. could not be known, therefore, water and soil sample within the survey area were collected and analysed in the laboratory. The concentration thus obtained has been used in this analysis. It should be noted here that since there is no reference dose factor (RfD) value for Pb and oral slope factor value for Cd mentioned by EPA, therefore, the non-carcinogenic risk of Pb and carcinogenic risk of Cd could not be assessed.

Table 5.8:Non-Carcinogenic Risk Factor (Cadmium)

Concentration of Cd: 0.018 mg/L

Medium: Water

Formula: Intake Rate, I = (C*CR*EF*ED)/(BW*AT)

Hazard Quotient, HQ = I/RfD

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (L/day)	Concentration, C (mg/L)	Intake rate, I (mg/kg.day)	Oral Reference Dose Factor, *RfD* (mg/kg.day)	Hazard Quotient, HQ	Comments
W-A	35	10	300	365	1	0.018	4.23×10^{-4}	5×10^{-4}	0.85(< 1)	Safe
W-B	50	10	300	365	1	0.018	2.96×10^{-4}	5×10^{-4}	0.59 (<1)	Safe
W-C	60	10	300	365	1	0.018	2.47×10^{-4}	5×10^{-4}	0.49 (< 1)	Safe

Table 5.9: Non-Carcinogenic Risk Factor (Chromium)

Concentration of Cr: 0.015 mg/L

Medium: Water

Formula: Intake Rate, I = (C*CR*EF*ED)/(BW*AT)

Hazard Quotient, HQ = I/RfD

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (L/day)	Concentration, C (mg/L)	Intake rate, I (mg/kg.day)	Oral Reference Dose Factor, *RfD* (mg/kg.day)	Hazard Quotient, HQ	Comments
W-A	35	10	300	365	1	0.015	3.52×10^{-4}	0.003	0.12 (< 1)	Safe
W-B	50	10	300	365	1	0.015	2.47×10^{-4}	0.003	0.09 (<1)	Safe
W-C	60	10	300	365	1	0.015	2.05×10^{-4}	0.003	0.07 (<1)	Safe

Table 5.10:Carcinogenic Risk Factor (Chromium)

Concentration of Cr: 0.015 mg/L

Medium: Water

Formula: Intake Rate, I = (C*CR*EF*ED)/(BW*AT)

Risk Factor, R = I ×SF

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (L/day)	Concentration, C (mg/L)	Intake rate, I (mg/kg.day)	Oral Slope Factor, SF (Table 5.1) $(mg/kg.day)^{-1}$	Risk factor	Comments
W-A	35	10	300	365	1	0.015	3.52×10^{-4}	0.5	1.76×10^{-4}	Acceptable
W-B	50	10	300	365	1	0.015	2.47×10^{-4}	0.5	1.24×10^{-4}	Acceptable
W-C	60	10	300	365	1	0.015	2.05×10^{-4}	0.5	1.03×10^{-4}	Acceptable

Table 5.11:Carcinogenic Risk Factor (Lead)

Concentration of Pb: 0.063 mg/L

Medium: Water

Formula: Intake Rate, I = (C*CR*EF*ED)/(BW*AT)

Risk Factor, R = I ×SF

Actual Event Duration: Life Time

Type of Case	Avg. Body Weight, BW (kg)	Exposure Duration, ED (hours/day)	Exposure Frequency, EF (days/year)	Period over which exposure is averaged, AT (days/year)	Contact Rate, CR (L/day)	Concentration, C (mg/L)	Intake rate, I (mg/kg.day)	Oral Slope Factor, SF (https://oehha.ca.gov/chemicals/lead-and-lead-compounds) $(mg/kg.day)^{-1}$	Risk factor	Comments
W-A	35	10	300	365	1	0.063	1.48×10^{-3}	8.5×10^{-3}	1.26×10^{-5}	Unacceptable
W-B	50	10	300	365	1	0.063	1.04×10^{-3}	8.5×10^{-3}	8.84×10^{-6}	Unacceptable
W-C	60	10	300	365	1	0.063	8.63×10^{-4}	8.5×10^{-3}	7.73×10^{-6}	Unacceptable

The analysis findings in Tables 5.8 -5.11 show that the concentration of Cd and Cr in water does not pose any risk (carcinogenic and non-carcinogenic) to the workers (all age group), whereas Pb concentration in water pose carcinogenic risk to all age groups of workers.

There exists a chance of health risk of workers due to dermal contact of such hazardous elements in e-wastes. Due to the absence of required data, such analysis could not be performed. Again, the present study could not find any scientific papers or supporting documents to support the risks posed by dermal contact of the toxic elements.

5.3 ASSESSMENT OF IMPACTS ON ENVIRONMENT

Inappropriate handling, recycling and disposal of e-wastes leads to an adverse effect on environment. The pathway can be of three routes: primary, secondary and tertiary. Primary source is the emission of hazardous elements (lead, mercury, cadmium, chromium, polychlorinated biphenyls etc.) from the e-wastes while handling and processing. Secondary source is the product of hazardous substance due to reaction of this elements such as furans, dioxins by inappropriate open burning of plastics with halogenated flame retardants. The tertiary route is the transport of such pollutants through air and water. Improper activities of e-waste recycling also a crucial source of environment-to-food-chain contamination as contamination may accumulate in agricultural lands and be available for uptake by grazing livestock. In addition, most chemicals of concern have a slow metabolic rate in animals and bioaccumulate in tissues and be excreted in edible products such as eggs and milk.

In Bangladesh, mainly in Dhaka city, open burning of wires/cables to recover copper is exercised by informal sector. This burning activity produces very harmful toxic compounds like dioxin and furanand causes air pollution. The e-wastes recycling activities are mainly concentrated in old parts of Dhaka (Islambag, Nimtoli, Chankharpool, Waizghat, Kamrangir Char) and the test results showed high concentration of iron, lead, Cadmium, Chromium content in surface water and soil in these areas (Chowdhury, 2014).Apart from e-wastes, a good number of different types of small factories, and specially tannery industries were located in these areas till 2016, and therefore it is very difficult to say that the pollution of heavy metals is solely contributed by e-wastes.More detail research should be performed to justify this.

Other than recovery and recycling, a considerable amount of e-wastes are mixed with the domestic solid wastes and are ended up in the landfill. The weathering action and chemical reaction accelerate the leaching of hazardous elements from e-wastes and release those in air, water and soil and thus pose a serious threat to the environment.

Chapter 6

Value Metal Recovery from Electronic waste

6.1 INTRODUCTION

Recovery of metals and precious metals from electronic waste (e-waste) has been an important topic not only for economic aspect but also for recycling rare natural sources and reducing the e-waste to prevent the environmental pollution. This chapter presents data concerning material composition of e-waste, with particular attention directed to the precious metals and possibility of their recovery from Printed Circuit Boards (PCBs) as main source of precious metals in e-waste are PCBs. In the current research hydrometallurgical process was used for effective recovery of the valuable metals (gold, silver, copper and tin) from waste printed circuit boards/RAMs since this is more suited to lab-scale experiments and much more environmentally friendly than pyrometallurgy. The methodology of this research work comprised of a systematic laboratory experimental research performed in the following sequence: i) Collection of PCBs/RAMs and other e-wastes from local market and local industries; ii) Characterization by AAS/XRF of elements present in the selected e-wastes (PCBs and RAM), iii) The e-wastes were subjected to an acid leaching process for metal (Gold, Silver, Copper and Tin) recovery using various process parameters.

6.2 COLLECTION OF PCB AND OTHER E-WASTEs

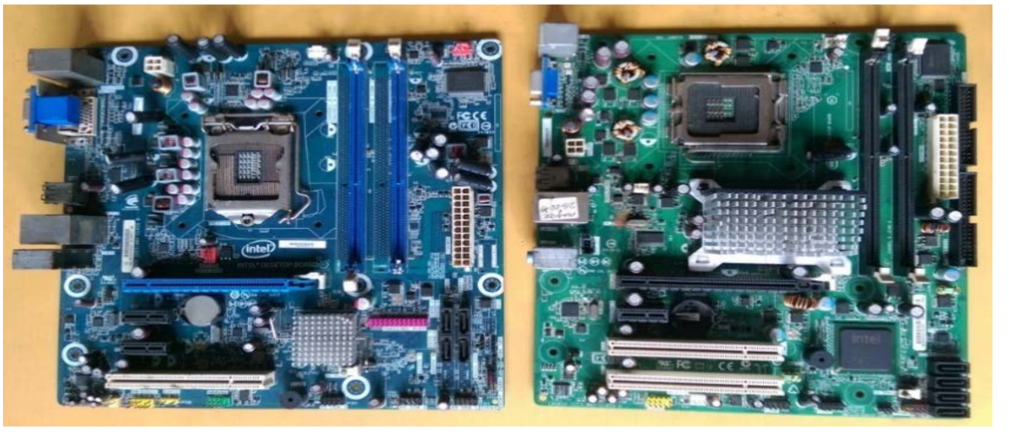
The research team visited the local markets of e-wastes such as Dholaikhal, Nimtoli and Elephant road and some active recycling and exporting industries named as Recycler 1, Recycler 2 and E-Waste Exporters. However, E-waste samples were collected from Nimtoli, Elephant road, Recycler 1 and Recycler 2. E-waste samples such as cell phones PCBs, computer motherboard, hard drive and RAM have been collected from Nimtoli and Elephant road area. Such e-wastes sample have also been collected from the Recycle Industry 1 and 2. Extracted metal, polymer and fibre powders are also collected from Recycle industry 1. Some high-grade PCBs and mother boards have been collected from Recycle industry 2. The collected samples are shown in Figures 6.1, 6.2 and 6.3.

Nokia PCBs

Chinese PCBs

RAM

Hard Disk



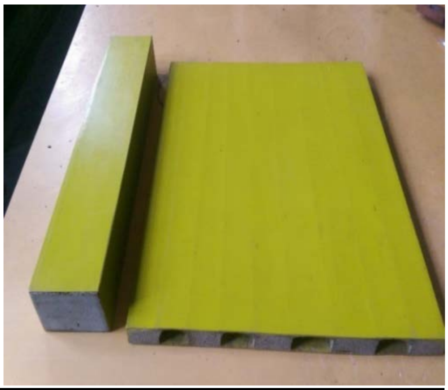
Computer PCB

Figure 6.1: E-Waste samples collected from local market

Metal Powder

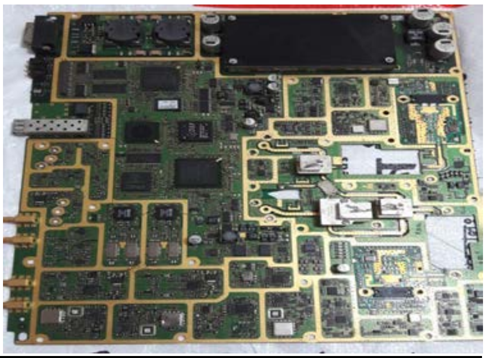
Fiber Glass (PCB Powder)

Polymer Powder



Composite made of Fiber and Polymer

Figure 6.2: Samples collected from Recycling Industry 1



Golden Board

Server Board

Navigation Board

AJB Board

Figure 6.3: Samples collected from Recycling Industry 2

6.3 SAMPLE SELECTION AND CHARACTERIZATION

According to observed recycling practices and the need of recovery solutions, Mobile PCBs and RAMs have been selected for extraction of value metals such as Silver, Gold, Copper and Tin. Metal powder collected from recycling industry 1 was studied to further extraction of Copper and Tin. The methods of characterization of the selected samples were based on the nature of the sample i.e. in solution or in powder form.

Two major instruments were used in the analysisof the elements in e-wastes in the present study. One was Atomic Absorption Spectroscopy (AAS), (Model: Varian AA 240 FS) which determines the concentration of elements in a liquid phase i.e. in mg/liter. The analysis has been performed by dissolving the PCBs/RAMs in the aqua regia solution. However, Gold characterization couldn't be done by AAS due to some limitation of the instrument. The other characterization method was performed using X-ray fluorescence spectroscopy (XRF) (Shimadzu Lab Center XRF-1800). This measures the concentration of elements in a powder sample which results in percentage of the composition. Figure 6.4shows the AAS and XRF equipment used in the study. In addition to this, microstructure of the gold pellets obtained in the gold extraction process was observed using a Field Emission Scanning Electron Microscope, model FEG-XL 30S by Jeol Ltd., at 5kV.

Initially the samples were weighed and dissolved in strong acidic solution of aqua regia. Conducting the dissolution under the fume hood is a must, as extremely toxic gases evolve during the reactions. Figure 6.5 shows the weighing and acid digestion of PCB samples under the fume hood.

(a) **(b)**

Figure 6.4: (a) AAS machine (b) XRF machine

(a)

(b)

(c)

Figure 6.5: (a) Weighing of samples for dissolution (b) Dissolution of PCB in aqua regia (c) Solution under Fume Hood

The % of dissolved metals in the solution was determined by Atomic Absorption Spectroscopy (AAS) of BCSIR. These solutions were further used for metal recovery process. The recovered metal powder (collected from Recycling industry 1) was characterized by XRF. Figure 6.6 shows the metal powder chosen for characterization and the apparatus for pressing them into tablets for XRF analysis.

(a)

(b)

Figure 6.6: (a) Metal Powder (b) Tablet making press

6.4 CHARACTERIZATION OF WASTE PCBS/RAMS/METAL POWDER

The PCBs/RAMS used in this study were prepared for chemical analysis by digestion with aqua regia. After digestion, the sample was filtered, and dilutions were made according to the element to be analyzed and the analysis method used: atomic absorption spectrometry (AAS). Leaching analyses were performed according to the Environmental Protection Agency (EPA) SW-846 test method. Table 6.1 shows the concentration of elements in each of the chosen samples analysed by AAS and XRF techniques. Five different kind of samples Nokia PCB, Chinese PCB, Computer PCB, RAM and metal powder from Recycler 1 were analyzed and the elemental compositions of different PCBs and RAMs were found to vary significantly. This is because the making of PCBs are diverse and complex in terms of type, size, shape, components, compositions and models and manufacturing company. Literature reviews have shown that there's a downward trend in precious metal content (gold, silver, cobalt, nickel etc.) in Smartphone PCBs so that Smartphone manufacturers may remain competitive in their market (Charles et al, 2017). In general, precious metal content is slightly less in Chinese PCB while cheap metal like Iron and harmful metals like Mercury and Lead are high. This is an offshoot of Chinese manufacturers minimizing their manufacturing cost.

Table 6.1: Amount of element present in different types of mobile PCB, Computer PCB and RAM

Elements	Concentration (mg/L)					Concentration (%wt.)
	Nokia PCB	Chinese PCB	Mobile PCB+ HNO_3	Compute r PCB	RAM	Metal powder of Recycler 1
Aluminum	746	753		699		0.68
Arsenic	<0.05	<0.05				--
Calcium	149	79.9	28.7	233	113.8	0.66
Cadmium	<0.01	0.18	<0.05	<0.02	<0.05	--
Chromium	266	278	6.5	957	4.39	0.02
Cobalt	32.5	9.04	28.4	28.7	48.1	--
Copper	25575	12825	18800	29450	66100	85.51
Iron	895	1528	4352	80700	4983	0.68
Lead	44	193	1270	12.8	600	3.24
Manganese	42.4	33.4	36.4	780	37.8	--
Mercury	<0.01	1.67	6.29	0.56	0.533	--
Molybdenum	14.2	3.59		85.8		--
Nickel	2263	733	3946	1175	3455	--
Silver	13.8	33.3	15.3	37.1	1.45	--
Tin	1835	1150		19480		3.44

**Gold concentration in the solution could not be determined due to lack of the appropriate radiation source in the testing equipment.

From Table 6.1, it can be seen that the waste PCBs contain significant amount of valuable/ precious metals such as Copper, Tin, Nickel, Silver etc. Gold concentration in the solution could not be determined due to lack of the appropriate radiation source in the testing equipment. The concentration of Copper was highest in the waste RAM (66100 g/L) and lowest in the Chinese PCBs (12825 mg/L). The Nokia mobile PCB and the Computer PCBs also show more that 25000 mg/L of Copper. The Tin content was the highest in Computer PCBs (19480 mg/L) and could not be determined in the waste RAMs. The mobile PCBs also contained more than 1000 mg/L of Tin. On the other hand, Chinese mobile shows 33.3 mg/L of silver,Nokia mobile shows 13.8 mg/L of silver and the highest amount of Silver was identified in Computer PCBs 37.1 mg/L. Some value metals like Calcium, Cobalt, Iron and Nickel are present in higher amounts in computer motherboard and RAM. However, these are also rich in toxic metals like Lead and have comparatively more Mercury than mobile PCB.

The mobile phone PCBs were directly dissolved in aqua regia. They did not go through any pre-mechanical treatment. On the other hand, the metal powder received from Recycler 1 was crushed and went through electrostatic separation in the factory. So, the metals were already separated from the non-metals. The XRF result of the metal powder received from Recycler 1 shows no Gold, Silver, Nickel or Manganese content. Copper (>85%) is the main component in the powder. Other metals like Aluminum, Iron and Tin are present in very low quantity. It is possible that either Recycler 1 had already separated the precious metals before handing us the sample, or the precious metals were present in such low quantities that the XRF software did not enlist them in the final result. Since silver, tin and copper were seen to be present in adequate amount in the PCBs and RAMs, these metals were chosen to be extracted. Gold quantity could not be measured because of technical difficulties, still gold was visible specially in the waste RAMs so it was also chosen.

In general, it is highly recommended to crush the PCBs into fine powders, separate metals and non-metals based on their differential densities & susceptibility to electromagnetic fields, then subject them to chemical separation processes. The increased surface area of the fine metal powders increases their reacti (b) eds up chemical reactions. The primary mechanical separation of the metals (a) tals also ensures that no undesirable by-product shows up when a specific metal is targeted for extraction. However, the required crushing and grinding apparatus were not available at the time of conducting the experiments, so chemical separation was directly carried out on whole PCBs.

6.5 VALUE METAL EXTRACTION

Four different types of value metals - Gold, Silver, Copper and Tin - were extracted from the collected electronic waste through hydrometallurgical route. This involves dissolving the waste PCB in a strong acidic solution such as aqua regia, then separating each of the value metals based on their reactivity by adjusting the pH and adding suitable reducing agents. However significant amount of Gold recovery was performed using another environment friendly process where aqua regia was not used. The methodology of valuable metal extractions is described in the following sections.

6.5.1 Methodology of Gold Extraction

Recycling of PCBs can only be profitable with substantial precious metal such as Gold or Silver recovery. In the current research gold extraction was carried out in two different methods from waste mobile phone PCBs and RAM samples. The first method was conventional aqua regia method described in Figure 6.10. In the second method the metallic components of waste RAMs were separated from non-metallic using DMA and ultrasonic treatment in order to facilitate the release of metallic materials, increase the final yield. Finally, the acid leaching process was employed to liberate gold from the gold-plated parts. This is one of the most advanced techniques and environment friendly procedures. This reverse engineering process is done by two major steps: at first, the Brominated Epoxy Resin was dissolved by DMA and in the later one, acid leaching was applied to separate the gold from RAM contacts.

Figure 6.9: Mobile PCBs & RAMs used in Gold extraction

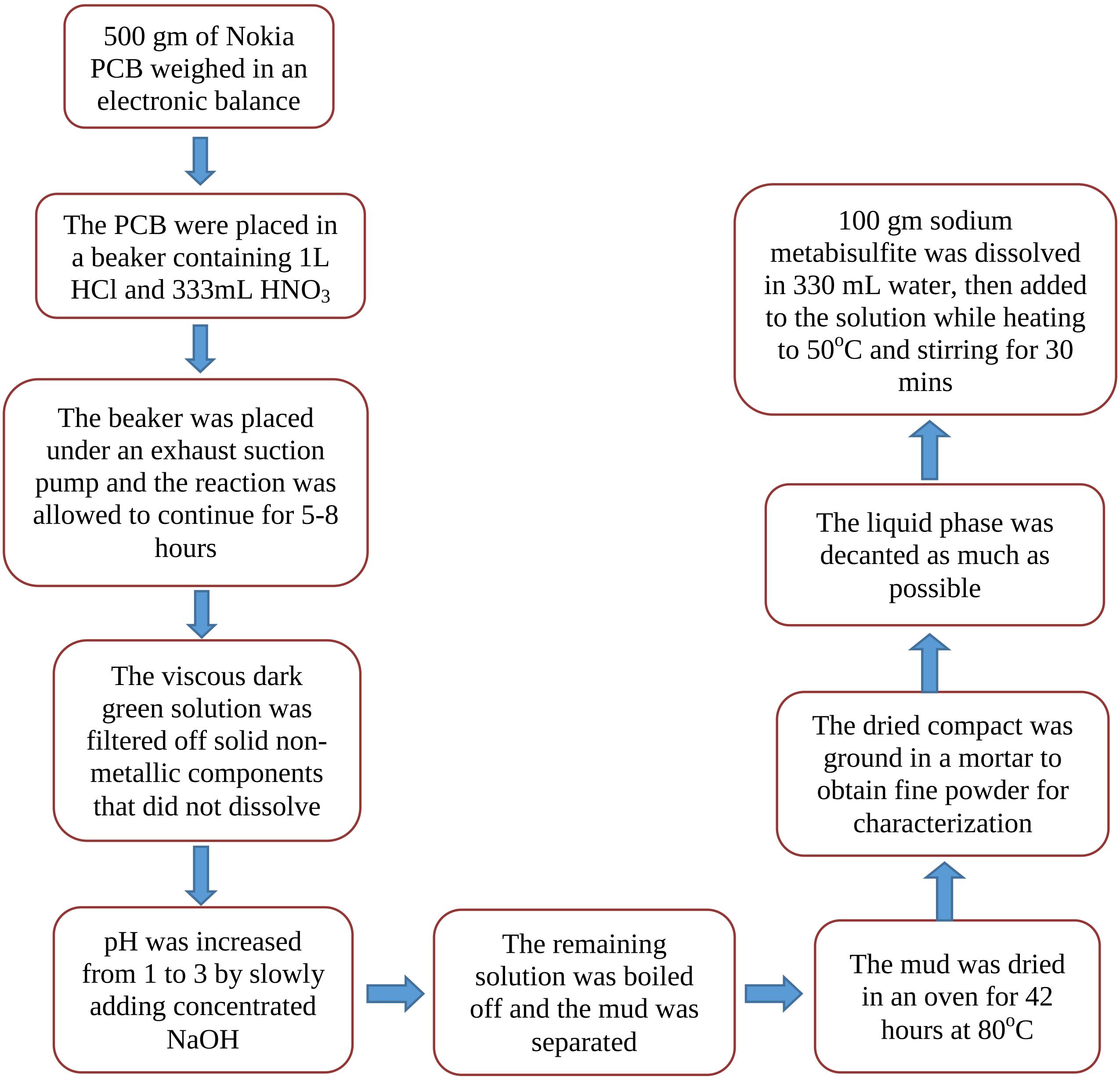


Figure 6.10: Flowchart of the Gold extraction process

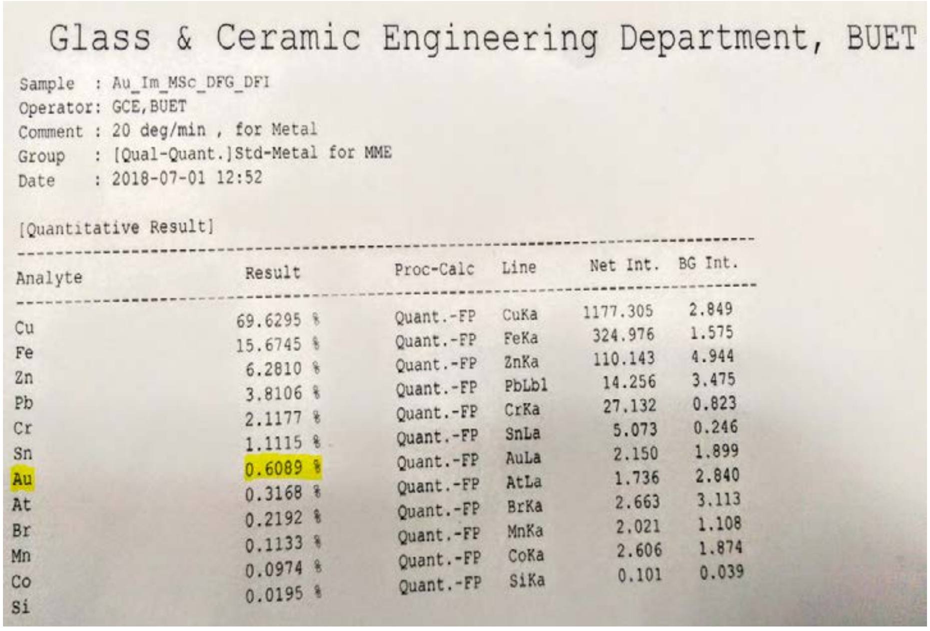
Figure 6.11: Leach liquor with brown mud

Figure 6.12: Brown mud with bluish green precipitate layer

Figure 6.13: Brown solid mass after drying at 100 degrees for 24 hours

Figure 6.14: Brown powder mass after grinding

Figure 6.15presents the XRF data of the powder found in method 1.



Glass & Ceramic Engineering Department, BUET

Sample : Au_Im_MSc_DFG_DFI
Operator: GCE,BUET
Comment : 20 deg/min , for Metal
Group : [Qual-Quant.]Std-Metal for MME
Date : 2018-07-01 12:52

[Quantitative Result]

Analyte	Result	Proc-Calc	Line	Net Int.	BG Int.
Cu	69.6295 %	Quant.-FP	CuKa	1177.305	2.849
Fe	15.6745 %	Quant.-FP	FeKa	324.976	1.575
Zn	6.2810 %	Quant.-FP	ZnKa	110.143	4.944
Pb	3.8106 %	Quant.-FP	PbLb1	14.256	3.475
Cr	2.1177 %	Quant.-FP	CrKa	27.132	0.823
Sn	1.1115 %	Quant.-FP	SnLa	5.073	0.246
Au	0.6089 %	Quant.-FP	AuLa	2.150	1.899
At	0.3168 %	Quant.-FP	AtLa	1.736	2.840
Br	0.2192 %	Quant.-FP	BrKa	2.663	3.113
Mn	0.1133 %	Quant.-FP	MnKa	2.021	1.108
Co	0.0974 %	Quant.-FP	CoKa	2.606	1.874
Si	0.0195 %	Quant.-FP	SiKa	0.101	0.039

Figure6.15: XRF Data of Powder Mass Obtained

The XRF result of the dried powder received from method 1 shows only 0.6% recovery of Gold, although according to scientific literature, this procedure should have given a very good yield of gold. The reason behind this could be the presence of high amount of Copper or other base metals in PCBs. The acid media contains too highly amount of these metals and they obstruct the cementation of gold and thus precipitation of those metals take place instead.

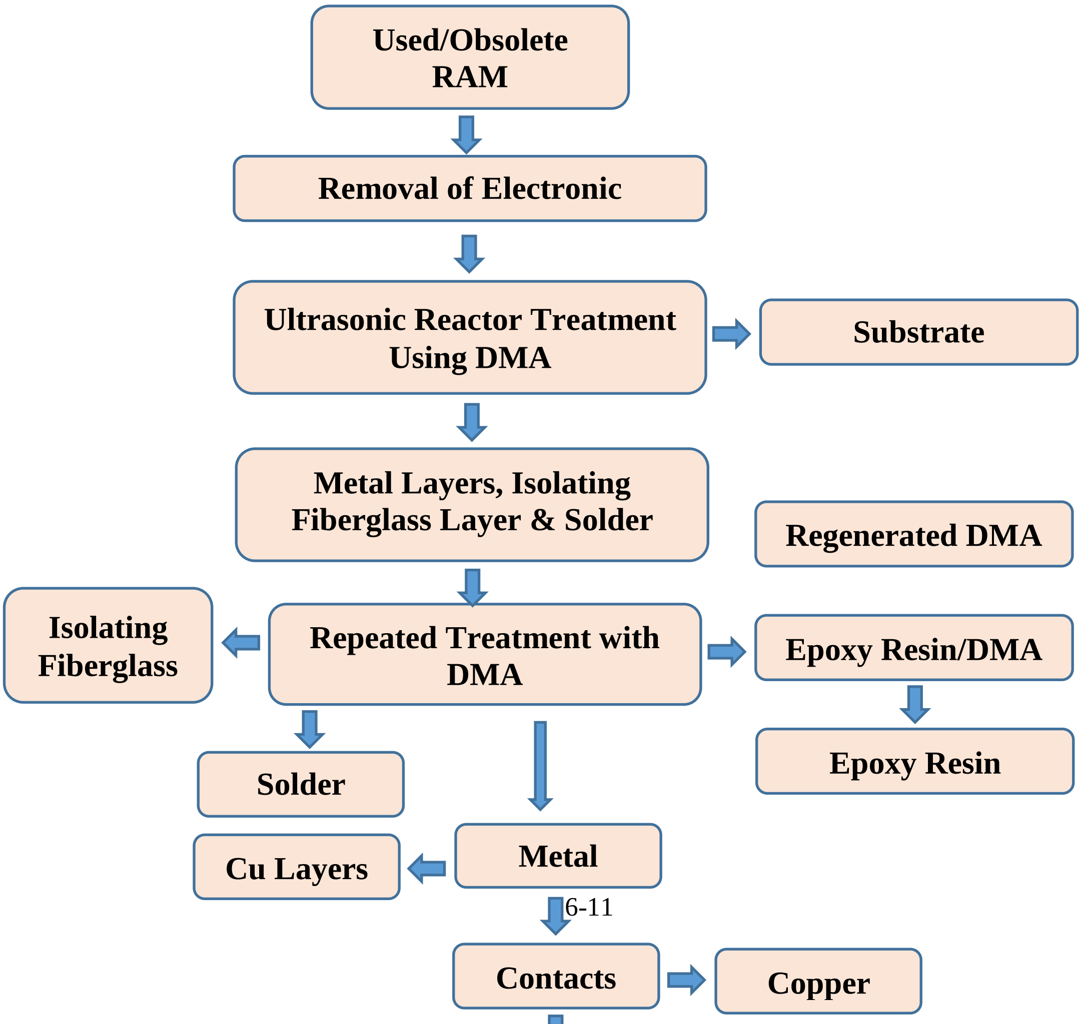


Figure 6.16: Process flow of Gold separation from RAM by DMA treatment

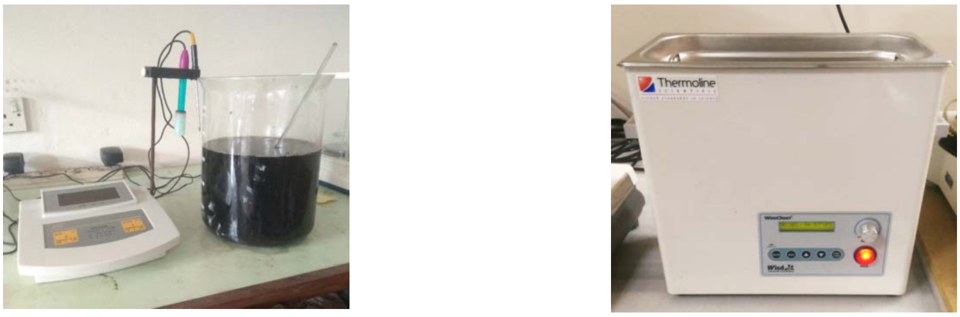


Figure 6.17: (a) pH meter (b) Ultrasonic Separator

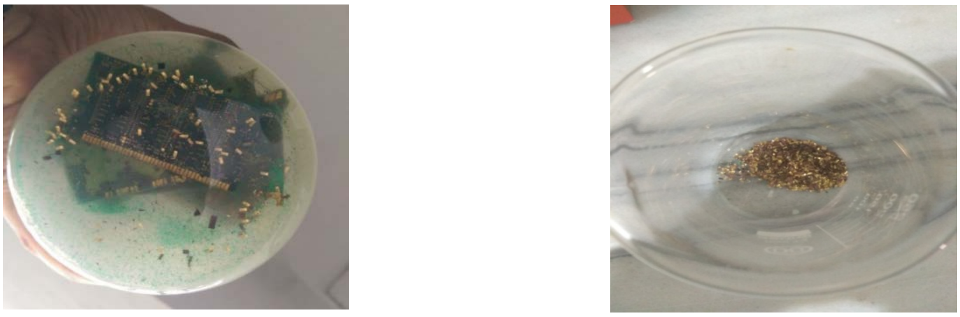


Figure 6.18: Gold separation by ultra-sonication with DMA

0.3 gm Gold was generated from 500 gm of waste RAMs. This approximate yield for Gold by the DMA process [method 2] followed in this experiment is quite higher than the literature value, which carried out precipitation reactions with strong reductant; this shows that DMA treatment is not just environmentally friendly but also highly effective. Conventional techniques like pyrolysis and chemical reduction have been shown to yield maximum 280 gm of gold per ton (Vidyadhar, 2016), whereas gold extraction using the DMA method in this experiment has shown to yield as much as 600 gm of gold per ton. It can be said that DMA treatment is very effective process that yielded pure gold even when it was present in trace amounts. Hence, this process holds high potential for commercial scale applications. Since we used only 500 gm of RAM chips for this lab-scale project, the amount of gold obtained may not appear to be significant. However, if tons of PCB are dealt in a pilot-plant scale project or industrially then a similar yield would amount to a substantial quantity of Gold.

The research team successfully recovered flake-shaped gold particles from full-size waste random access memory (RAM) after separation of all metallic and non-metallic components of RAM by using organic solvent and ultrasonication treatment. The separation of the RAM took approximately 24 hours due to its complex structure. 500 gm of waste RAMs were found to contain 0.3 gm of gold; therefore, the developed technique is capable of recovering > 600 gm of gold from one ton of waste RAMs. Based on the available literature, this technology seems to be promising in terms of profitability, especially due to the high gold recovery rate, possibility to combine it with biohydrometallurgy, and industrial scalability.

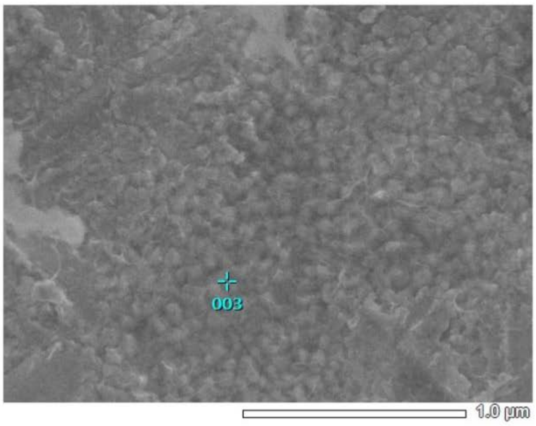
The amount of gold dissolved in the leach liquor could not be identified due to limitations of the equipment, so process efficiency of gold extraction in this experiment could not be calculated. However, the microstructure of the gold pellets was observed using Field Emission Scanning Electron Microscope, model FEG-XL 30S by Jeol Ltd., at 5kV. Figure 6.19 shows Electron Diffraction Spectroscopic (EDS) data of two points on the microstructure of the gold pellets. EDS data gives an idea of the percentage of different elements present in a solid sample.

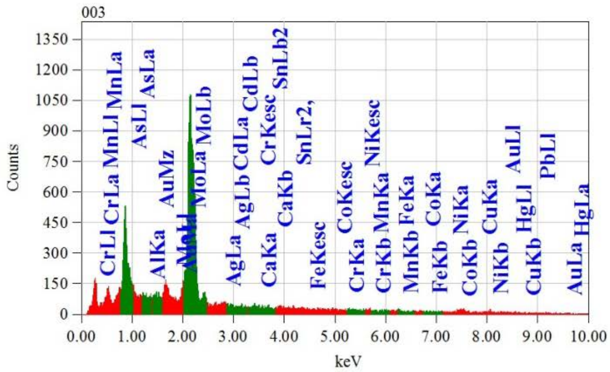
View001

JEOLUSER 1/1

Title : IMG1

Instrument : 7600F
Volt : 5.00 kV
Mag. : x 50,000
Date : 2018/09/26
Pixel : 512 x 384





Acquisition Parameter
Instrument : 7600F
Acc. Voltage : 10.0 kV
Probe Current: 1.00000 nA
PHA mode : T3
Real Time : 30.45 sec
Live Time : 30.00 sec
Dead Time : 1 %
Counting Rate: 1685 cps
Energy Range : 0 - 20 ke\

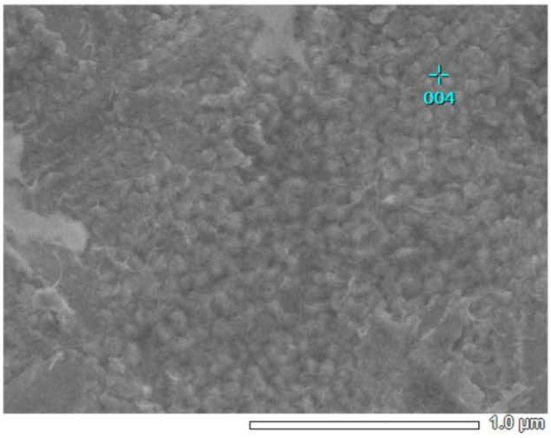
ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.2378

Element	(keV)	Mass%	Sigma	Atom%	Compound	Mass%	Cation	K
Al K	1.486	0.14	0.06	0.64				0.1815
Ca K	3.690	0.25	0.11	0.76				0.3895
Cr K	5.411	0.02	0.22	0.06				0.0383
Mn K								
Fe K								
Co K								
Ni L	0.851	24.65	0.57	50.38				23.6894
Cu L	0.930	1.64	0.12	3.10				2.8781
As L								
Mo L								
Ag L	2.983	0.41	0.18	0.45				0.4354
Cd L	3.132	0.29	0.19	0.31				0.3144
Sn L	3.442	0.41	0.25	0.41				0.4363
Au M	2.121	63.96	0.55	38.97				63.4615
Hg M	2.195	8.22	0.52	4.92				8.1757
Pb M								
Total		100.00		100.00				

(a)

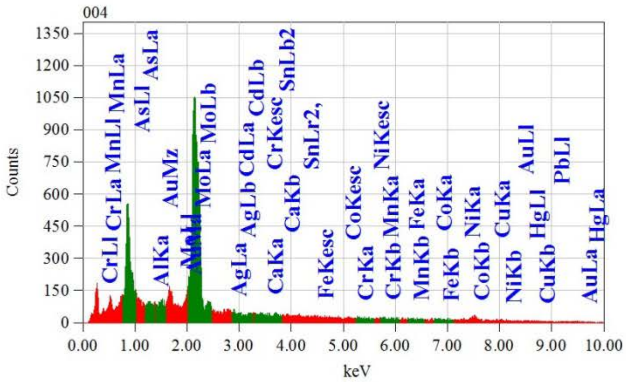
View001

JEOLUSER 1/1



Title : IMG1

Instrument : 7600F
Volt : 5.00 kV
Mag. : x 50,000
Date : 2018/09/26
Pixel : 512 x 384



Acquisition Parameter
Instrument : 7600F
Acc. Voltage : 10.0 kV
Probe Current: 1.00000 nA
PHA mode : T3
Real Time : 30.47 sec
Live Time : 30.00 sec
Dead Time : 1 %
Counting Rate: 1763 cps
Energy Range : 0 - 20 keV

ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.2475

Element	(keV)	Mass%	Sigma	Atom%	Compound	Mass%	Cation	K
Al K	1.486	0.12	0.06	0.52				0.1510
Ca K	3.690	0.52	0.12	1.54				0.8037
Cr K								
Mn K								
Fe K								
Co K								
Ni L	0.851	25.58	0.70	51.49				24.7959
Cu L	0.930	1.32	0.13	2.45				2.3069
As L	1.282	0.42	0.13	0.67				0.3914
Mo L								
Ag L	2.983	0.37	0.18	0.40				0.3924
Cd L								
Sn L								
Au M	2.121	64.60	0.82	38.76				64.1145
Hg M	2.195	7.08	0.56	4.17				7.0441
Pb M								
Total		100.00		100.00				

JEOL

(b)

Figure 6.19: Microstructure of gold pellets showing elemental composition by Energy Dispersive Spectroscopy

Gold coatings are actually alloys of gold with other metals like nickel and cobalt to confer the right mix of mechanical and electrical properties. As such, metals other than gold are present in the microstructure. These are grains of alloying elements interspersed with grains of gold. Regardless, the high percentage of gold visible in the EDS data confirms that gold was indeed present in the pellets obtained by the DMA method.

6.5.2 Methodology of Silver Extraction

In the present research, to recover silver from the waste PCBs, two different methods were used. These methods are shown in the flowchart (Figure 6.20) and different stages of silver extraction are shown in Figure 6.21- 6.24.Finally, the recovered silver content from two different methods are shown in Table 6.2 and the test reports are shown in Figure 6.25-6.26.

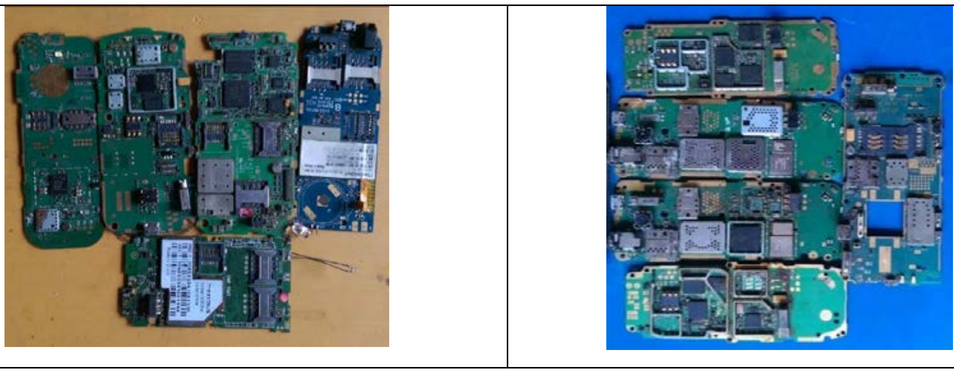


Figure 6.19 Mobile PCBs for Silver Extraction

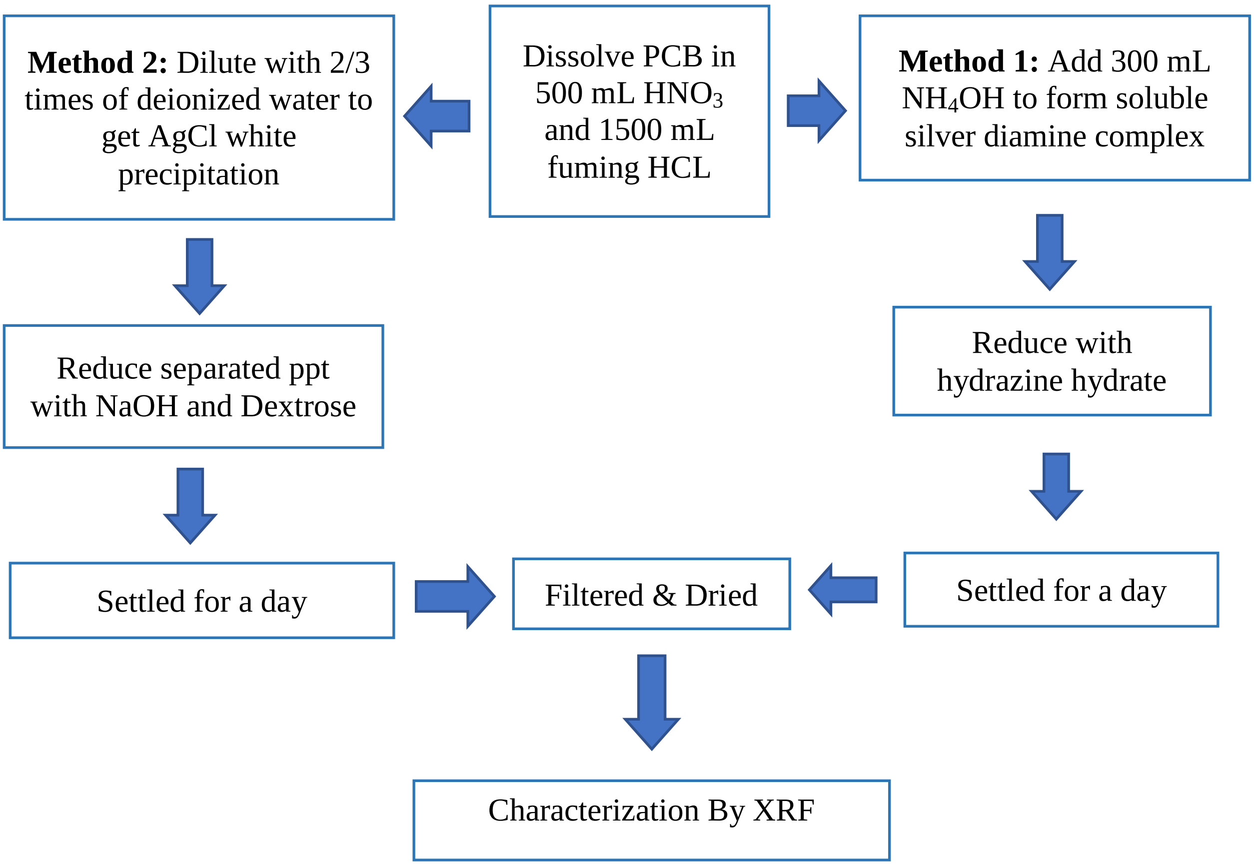


Figure 6.20: Flow chart of Ag extraction from PCB

Figure 6.21: Aqua regia dissolution of PCB

(a) **(b)**

Figure 6.22: (a) AgCl precipitate at the bottom (b) Solid powder for characterization

(a) **(b)**

Figure 6.23: (a) AgCl precipitate at the bottom (b) Solid powder for characterization

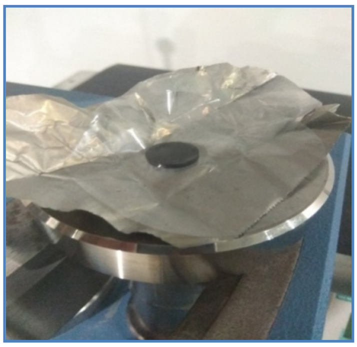


Figure 6.24: SilverTablet Sample for XRF Analysis

Sample : Ag_B_Im_DFG_MME
Operator: GCE,BUET
Comment : 20 deg/min , for Metal
Group : [Qual-Quant.]Std-Metal for MME
Date : 2018-09-03 14:17

[Quantitative Result]

Analyte	Result	Proc-Calc	Line	Net Int.	BG Int.
Cu	61.7298 %	Quant.-FP	CuKa	125.140	0.406
Fe	5.4341 %	Quant.-FP	FeKa	10.897	0.145
Sn	5.3932 %	Quant.-FP	SnLa	2.307	0.215
Ni	5.0958 %	Quant.-FP	NiKa	10.439	0.273
Zn	4.1517 %	Quant.-FP	ZnKa	7.872	0.572
Ag	3.6752 %	Quant.-FP	AgKa	2.311	1.480
Na	3.6435 %	Quant.-FP	NaKa	0.203	0.004
Ru	3.2491 %	Quant.-FP	RuKa	3.498	3.569
Si	2.5084 %	Quant.-FP	SiKa	1.400	0.018
Br	1.1809 %	Quant.-FP	BrKa	1.675	0.428
Ca	1.0036 %	Quant.-FP	CaKa	1.510	0.362
Cr	0.8935 %	Quant.-FP	CrKa	0.965	0.077
Pb	0.6067 %	Quant.-FP	PbLb1	0.268	0.509
Nb	0.5174 %	Quant.-FP	NbKa	1.202	1.050
P	0.2560 %	Quant.-FP	P Ka	0.349	0.058
S	0.2535 %	Quant.-FP	S Ka	0.245	0.089
K	0.2477 %	Quant.-FP	K Ka	0.407	0.188
Mn	0.1058 %	Quant.-FP	MnKa	0.170	0.115
Al	0.0542 %	Quant.-FP	AlKa	0.045	0.012

Figure 6.25: XRF Result of Recovered Silver Powder from Method 1.

Glass & Ceramic Engineering Department, BUET

Sample : Pow_Ag_AH_DFG_MME
Operator: GCE,BUET
Comment : 20 deg/min , for Metal
Group : [Qual-Quant.]Std-Metal for MME
Date : 2018-09-09 10:25

[Quantitative Result]

Analyte	Result	Proc-Calc	Line	Net Int.	BG Int.
Ag	94.6785 %	Quant.-FP	AgKa	90.690	1.114
Fe	2.1085 %	Quant.-FP	FeKa	2.628	0.073
Cu	1.3434 %	Quant.-FP	CuKa	3.228	0.143
Sn	0.7876 %	Quant.-FP	SnLa	0.278	0.152
Si	0.5284 %	Quant.-FP	SiKa	0.801	0.018
Cr	0.2424 %	Quant.-FP	CrKa	0.159	0.051
Ru	0.2204 %	Quant.-FP	RuKa	0.657	1.499
Ni	0.0613 %	Quant.-FP	NiKa	0.126	0.105
P	0.0293 %	Quant.-FP	P Ka	0.109	0.054

Figure 6.26: XRF Result of Recovered Silver Powder from Method 2

From the XRF results (Figure 6.25-6.26), it can be seen that, more than 94% silver was recovered by method 2 whereas method 1 shows only 3.7% recovery. The results are summarized in weight in Table 6.2.

Table 6.2: Recovered Silver Content in two different methods

Method	Recovered Silver Content
1	3.70%
2	94.68%

6.5.3 Methodology of Copper Extraction

After precious metals, copper is the next highest value metal to be extracted from e-waste. From the AAS result it can be seen that copper has the highest concentration among 5 different types of e-waste. In this research 3 batches of Mobile PCBs and 3 batches of metal powder samples (collected from Recycler 1) were used to extract copper (Table 6.3). Two different acids were used for leaching – HCl and H_2SO_4. The Copper extraction procedure is shown in the flowchart (Figure 6.27) and different stages of Copper extraction are shown in Figure 6.28-6.32. The XRF results of recovered copper content from six different samples are shown in Table 6.4 and Figure 6.33 shows the test reports.

Table 6.3: Procedures of Cu Extraction for Six Samples

Sample	Procedures
1	Metal powder, Electrolysis, HCl+ H_2O_2
2	Metal powder, Electrolysis, H_2SO_4+H_2O_2
3	Metal powder, Al foil, HCl+H_2O_2
4	Mobile PCBs, Electrolysis, H_2SO_4+H_2O_2
5	Mobile PCBs, Electrolysis, HCl+H_2O_2
6	Mobile PCBs, Al foil, HCl+H_2O_2

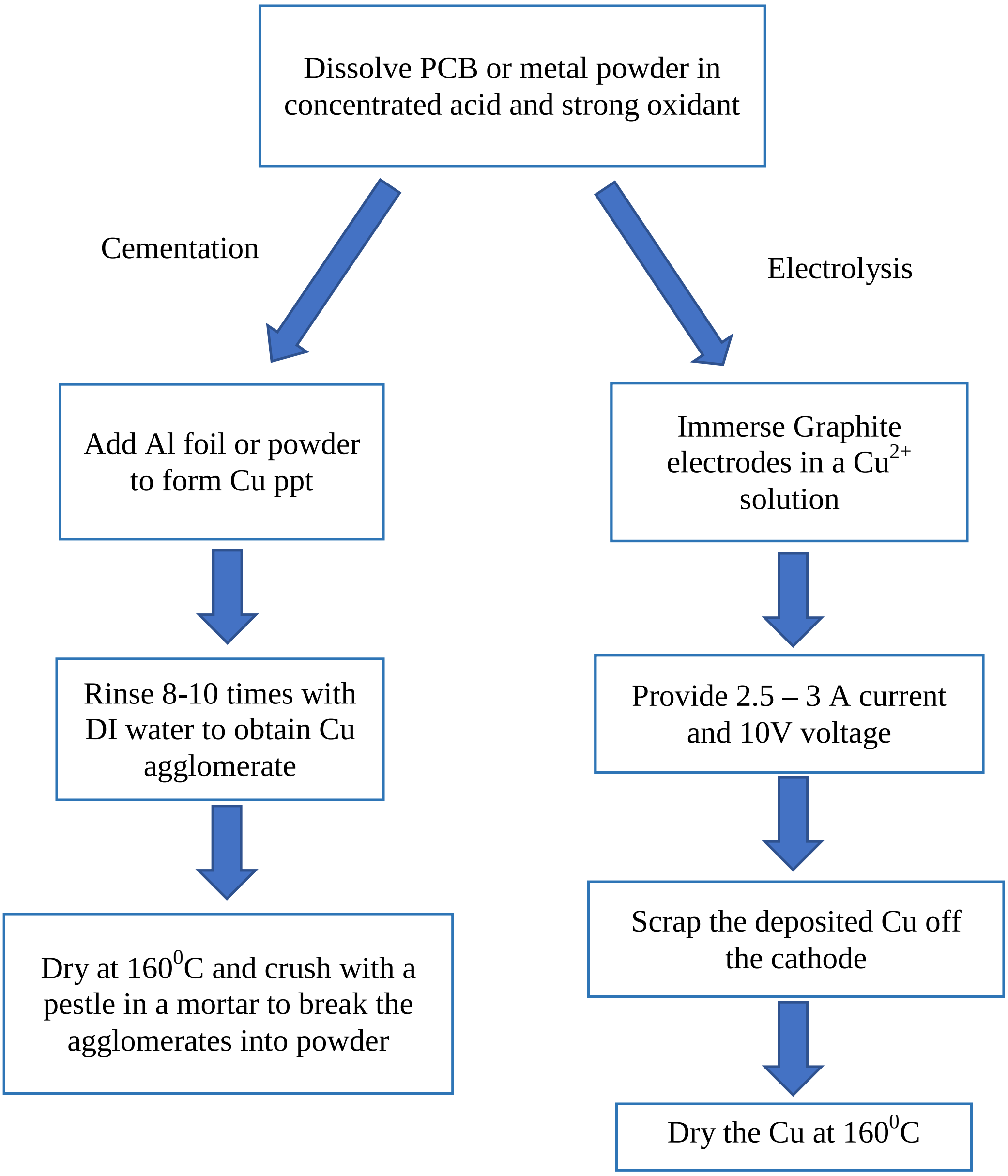
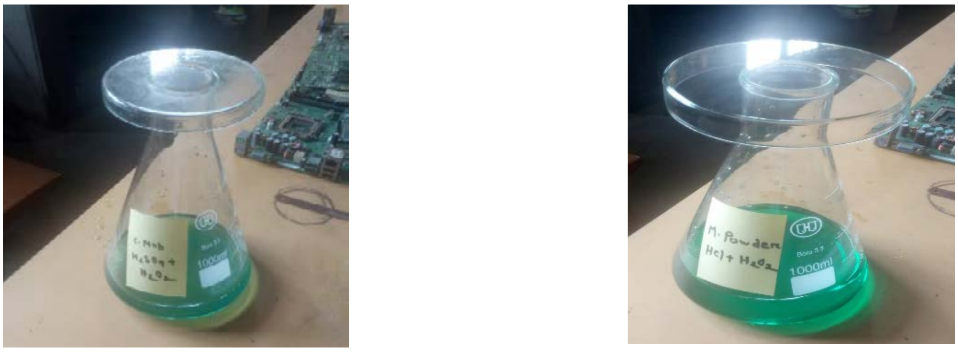


Figure 6.27: Flow chart of the different processes of Cu extraction

(a) (b)

Figure 6.28: (a) Weighing of the PCB in electric balance (b) Dissolving PCB in acid solution



(a) (b)

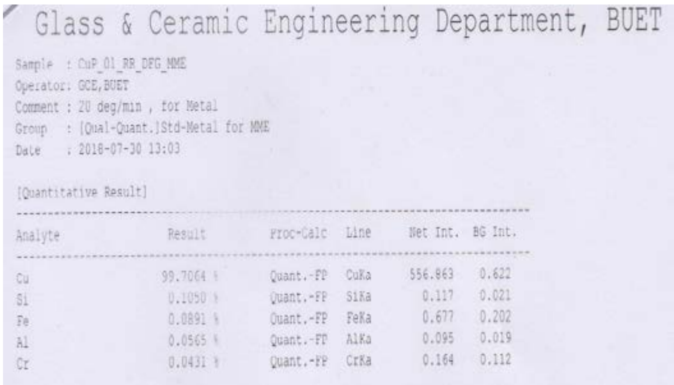
Figure 6.29: (a) Mobile PCBs (b) Metal powder dissolved in acid + H_2O_2

(a) (b)

Figure 6.30: (a) Cementation reaction on adding Al (b) Drying of filtered Cu precipitate

Figure 6.31: Electrolysis and Cu deposits on cathode

Figure 6.32: Dried Cu Powder from Graphite Cathode



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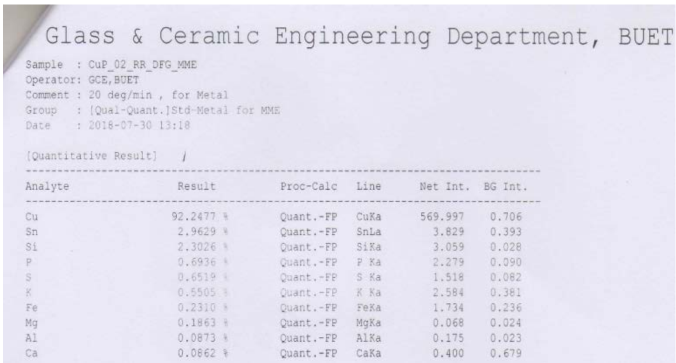
Sample : CuP_01_RR_DFG_MME
Operator: GCE,BUET
Comment : 20 deg/min , for Metal
Group : [Qual-Quant.]Std-Metal for MME
Date : 2018-07-30 13:03

[Quantitative Result]

Analyte	Result	Proc-Calc	Line	Net Int.	BG Int.
Cu	99.7064 %	Quant.-FP	CuKa	556.863	0.622
Si	0.1050 %	Quant.-FP	SiKa	0.117	0.021
Fe	0.0891 %	Quant.-FP	FeKa	0.677	0.202
Al	0.0565 %	Quant.-FP	AlKa	0.095	0.019
Cr	0.0431 %	Quant.-FP	CrKa	0.164	0.112

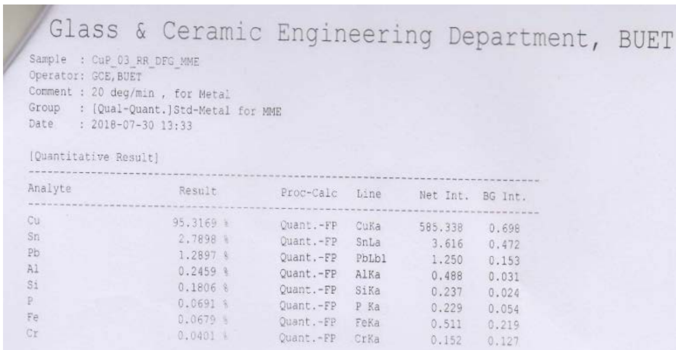


Glass & Ceramic Engineering Department, BUET

Sample : CuP_02_RR_DFG_MME
Operator: GCE,BUET
Comment : 20 deg/min , for Metal
Group : [Qual-Quant.]Std-Metal for MME
Date : 2018-07-30 13:18

[Quantitative Result]

Analyte	Result	Proc-Calc	Line	Net Int.	BG Int.
Cu	92.2477 %	Quant.-FP	CuKa	569.997	0.706
Sn	2.9629 %	Quant.-FP	SnLa	3.829	0.393
Si	2.3026 %	Quant.-FP	SiKa	3.059	0.028
P	0.6936 %	Quant.-FP	P Ka	2.279	0.090
S	0.6519 %	Quant.-FP	S Ka	1.518	0.082
K	0.5505 %	Quant.-FP	K Ka	2.584	0.381
Fe	0.2310 %	Quant.-FP	FeKa	1.734	0.236
Mg	0.1863 %	Quant.-FP	MgKa	0.068	0.024
Al	0.0873 %	Quant.-FP	AlKa	0.175	0.023
Ca	0.0862 %	Quant.-FP	CaKa	0.400	0.679

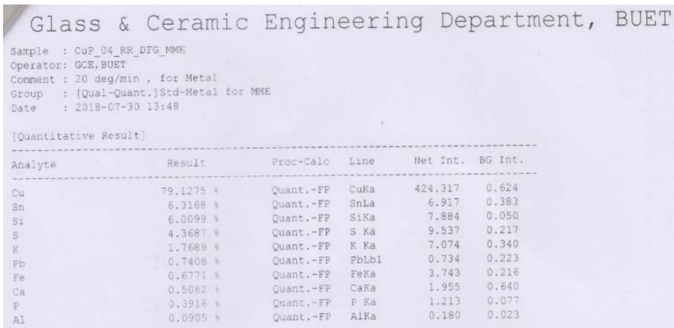


Glass & Ceramic Engineering Department, BUET

Sample : CuP_03_RR_DFG_MME
Operator: GCE,BUET
Comment : 20 deg/min , for Metal
Group : [Qual-Quant.]Std-Metal for MME
Date : 2018-07-30 13:33

[Quantitative Result]

Analyte	Result	Proc-Calc	Line	Net Int.	BG Int.
Cu	95.3169 %	Quant.-FP	CuKa	585.338	0.698
Sn	2.7898 %	Quant.-FP	SnLa	3.616	0.472
Pb	1.2897 %	Quant.-FP	PbLb1	1.250	0.153
Al	0.2459 %	Quant.-FP	AlKa	0.488	0.031
Si	0.1806 %	Quant.-FP	SiKa	0.237	0.024
P	0.0691 %	Quant.-FP	P Ka	0.229	0.054
Fe	0.0679 %	Quant.-FP	FeKa	0.511	0.219
Cr	0.0401 %	Quant.-FP	CrKa	0.152	0.127

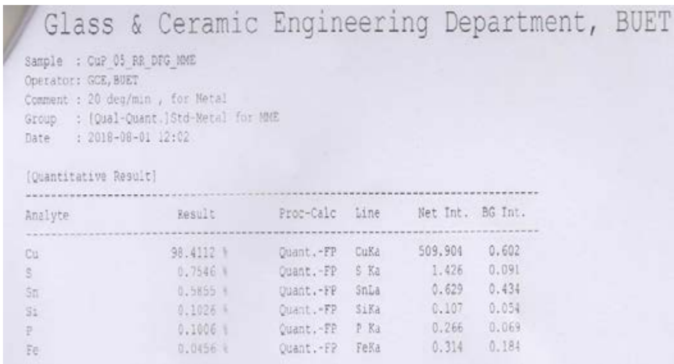


Glass & Ceramic Engineering Department, BUET

Sample : CuP_04_RR_DFG_MME
Operator: GCE,BUET
Comment : 20 deg/min , for Metal
Group : [Qual-Quant.]Std-Metal for MME
Date : 2018-07-30 13:48

[Quantitative Result]

Analyte	Result	Proc-Calc	Line	Net Int.	BG Int.
Cu	79.1275 %	Quant.-FP	CuKa	424.317	0.624
Sn	6.3168 %	Quant.-FP	SnLa	6.917	0.383
Si	6.0099 %	Quant.-FP	SiKa	7.884	0.050
S	4.3687 %	Quant.-FP	S Ka	9.537	0.217
K	1.7689 %	Quant.-FP	K Ka	7.074	0.340
Pb	0.7408 %	Quant.-FP	PbLb1	0.734	0.223
Fe	0.6771 %	Quant.-FP	FeKa	3.743	0.216
Ca	0.5082 %	Quant.-FP	CaKa	1.955	0.640
P	0.3916 %	Quant.-FP	P Ka	1.213	0.077
Al	0.0905 %	Quant.-FP	AlKa	0.180	0.023



Glass & Ceramic Engineering Department, BUET

Sample : CuP_05_RR_DFG_MME
Operator: GCE,BUET
Comment : 20 deg/min , for Metal
Group : [Qual-Quant.]Std-Metal for MME
Date : 2018-08-01 12:02

[Quantitative Result]

Analyte	Result	Proc-Calc	Line	Net Int.	BG Int.
Cu	98.4112 %	Quant.-FP	CuKa	509.904	0.602
S	0.7546 %	Quant.-FP	S Ka	1.426	0.091
Sn	0.5855 %	Quant.-FP	SnLa	0.629	0.434
Si	0.1026 %	Quant.-FP	SiKa	0.107	0.054
P	0.1006 %	Quant.-FP	P Ka	0.266	0.069
Fe	0.0456 %	Quant.-FP	FeKa	0.314	0.184

Figure 6.33: XRF Results of Recovered Copper Samples

Table 6.4:Recovered Copper Content in Six Samples

Sample	Recovered Copper Content
1	99.7%
2	92.3%
3	95.3%
4	79.1%
5	98.4%
6	88.9%

From the XRF results it can be seen that more than 90% copper recovery was achieved which indicates very high efficiency. It can be said that copper was effectively and selectively recovered from waste PCBs. The highest recovery was 99.7 % however the lowest value of recovery was near 80%, which can be attributed to the low volume of acid used. Hence, regardless of electrolysis or sedimentation method of Cu extraction, high volume of acid solution is recommended to achieve greater than 90% efficiency of Cu extraction.

6.5.4 Methodology of Tin Extraction

Metal powder and mobile PCBs were used to recover tin. The tin recovery process is shown in the flowchart (Figure 6.35). The recovered tin powder was analyzed by XRF and the test result is shown in figure 6.37. 86% Tin recovery was achieved through this process.

Figure 6.34: Metal powder and Mobile PCBs samples

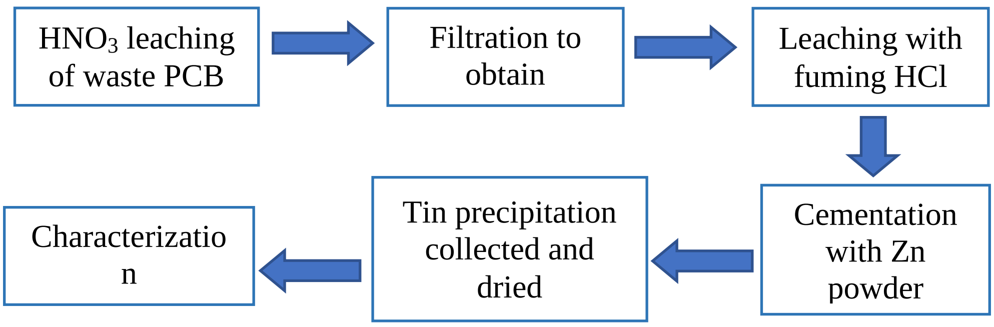


Figure 6.35: Flow diagram for Tin extraction

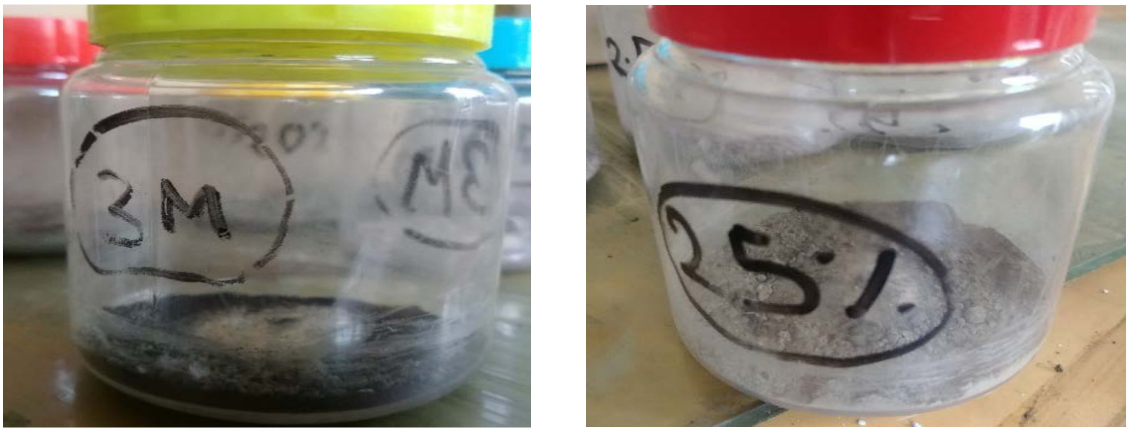
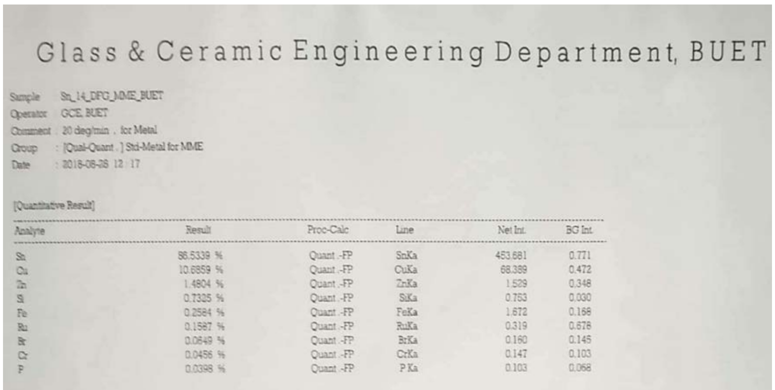


Figure 6.36: Recovered Tin from different samples



Glass & Ceramic Engineering Department, BUET

Sample Sn_14_DFG_MME_BUET
Operator GCE, BUET
Comment : 20 deg/min , for Metal
Group : [Qual-Quant .] Std-Metal for MME
Date : 2018-08-28 12 : 17

[Quantitative Result]

Analyte	Result	Proc-Calc	Line	Net Int.	BG Int.
Sn	86.5339 %	Quant .-FP	SnKa	453.681	0.771
Cu	10.6859 %	Quant .-FP	CuKa	68.389	0.472
Zn	1.4804 %	Quant .-FP	ZnKa	1.529	0.348
Si	0.7325 %	Quant .-FP	SiKa	0.753	0.030
Fe	0.2584 %	Quant .-FP	FeKa	1.672	0.168
Ru	0.1587 %	Quant .-FP	RuKa	0.319	0.678
Br	0.0649 %	Quant .-FP	BrKa	0.160	0.145
Cr	0.0456 %	Quant .-FP	CrKa	0.147	0.103
P	0.0398 %	Quant .-FP	P Ka	0.103	0.068

Figure 6.37: XRF result of Tin recovered from Mobile PCBs

Research limitations: E-waste consists of several components in the form of metals and multi-material elements. The base metals include iron, copper, aluminum, nickel, zinc, selenium, indium, gallium and precious metals. Hazardous substances that can be found in e-waste, include: mercury, beryllium, lead, arsenic, cadmium, antimony. In addition, the large material group consists of plastics, glass and ceramics. Recovery of desired material with such a diverse group of waste requires the use of complex technology recycling. The biggest problem is a necessity of applying different technologies for the processing of various materials, which are extracted in the subsequent stages of recycling. In the adopted experimental conditions, precious metals have not been effectively recovered in some cases. Material complexity of PCBs complicated the hydrometallurgical processes and can reduce the effectiveness of metals recovery.

6.6 FINDINGS

This study has successfully demonstrated the recovery of value metals namely gold, silver, copper and tin from mobile phone and computer PCBs and RAM.Through hydrometallurgical process routes significant amount of value metals were recovered. Copper, Tin and Silver showed corresponding metal recovery of 99.7%, 86%, 94% respectively. Analysis by XRF has confirmed the recovery of these precious metals. The recoveries in all the cases were in good agreement with examples found in literature.The amount of metal obtained was used to approximate average yield of each element from 1 ton of waste PCB. The result is summarised in Table 6.5.

Table 6.5: Comparison of yield value from experiment with reference value

Recovered Metal	1 ton PCBs/RAMs (present study)	1 ton PCBs/RAMs (Reference value)	Market Value (USD/gm)	Value Recovered (USD)
Gold	600 gm	279.93 gm (Vidyadhar, 2016) 1000 gm (Bidini et al. 2015)	38	$22,800
Silver	7.6 kg	7.2 kg (Bidini et al. 2015)	0.46	$3496
Copper	136.35 kg	190.512 kg (Vidyadhar, 2016)	0.01	$1363
Tin	24 kg	30.84 kg (Vidyadhar, 2016)	0.03	$720

The presence of precious metals quantity should encourage the formal recyclers and attract the informal recyclers towards the formal recycling. The precious metal yield results may be used for the installation of separate recycling infrastructure particularly for mobile phone waste. In Bangladesh an immense amount of precious metals is exported or wasted which cause air pollution, contaminating natural resources and harming soil fertility. This study endeavors to go into the interiors of the metal recovery and assessment from discarded mobile phone and computer PCBs. All in all, waste PCB found in discarded electronic products are anything but *waste*. If these printed circuit boards are retrieved and subjected to proper processing techniques, the amount of value metals generated will contribute a lot of value to the economy. The lab works detailed in this report shows that value metal extraction from waste PCB/RAM has high potential and merits government and private sector investment into research to determine ideal processing parameters that will push up the value metal yield while cutting down operating costs.

Chapter 7

Discussion

7.1 INTRODUCTION

The present action-based research was undertaken with an objective of evaluating the existing data on the flow of e-wastes in Bangladesh and estimating the future trend of e-waste generation. Apart from these objectives, it also aimed to assess the impacts of e-wastes on human health and environment and also investigate the resource recovery potential from e-wastes in an environmentally friendly way.Keeping these objectives in view, the research was designed and conducted accordingly and the results and findings are presented in Chapter 4, 5 and 6. This chapter presents a detailed discussion on theseresults and findings which summarizes the overall outcome of the study. The discussion is presented in view of the broad objective of the study in the light of the outcomes of this research activities.

7.2 DISCUSSION ON ASSESSMENT OF E-WASTES GENERATION AND ITS FUTURE TREND

The present study has adopted two approaches to assess the types and amounts of e-wastes in Bangladesh. The first approach is based on sale/import data of electrical and electronic items in the market and after their end of life and the amount of wastes was estimated by mathematical model (Chapter 4, Section 4.2). The second approach is based on primary data collected from questionnaire survey, field visits, interviews and a number of formal and informal meetings with the stakeholders.E-wastes amounts cited in the previous studies have also been reviewed and analyzed (Chapter 2 and Chapter 4).

The estimated e-waste growth of Bangladesh is shown in Figure 4.17, Chapter 4. From this figure it is observed that at present (2018), amount of e-waste is 0.40 million ton and by the 2035 the amount is estimated to be 4.62 million tonwith an annual growth rate is around 20% per year. This is quite a high rate of growth which may be attributed to the rapid industrialization and urbanization that Bangladesh is going through, and the extensive use of electronic appliances in households, industry and business, in conformity with the increasing purchasing power of the population.Moreover, the modern-day manufacturing world's philosophy is to produce short life, cheap products and thereby contributing more wastes. According to the report of 'The Global E-Waste Monitor' (Balde et al., 2017), the world's total e-waste amount is 44.7 million tonin year 2016 among which 18.2 million ton is contributed by Asia (49 countries of Asia). Compared to the amount of China (7.21 million ton) and India (1.97 million ton) in year 2016, (Balde et. al, 2017) the estimation for Bangladesh in the present study (0.31 million ton)appears to be logical. Table 7.1 shows a comparison of the estimated amount of e-wastesin year 2016for Bangladesh in the present study with the findings of previous studies.

Table 7.1: Comparison of E-Wastes in Bangladesh for year 2016 among different Studies

ESDO (2016)	Balde et al. (2017)	Present Study (2018)
9.81 Million Ton	**0.142 Million Ton**	**0.31 Million Ton**

It has been observed from Table 7.1 that the estimated amount in the three studies vary in a wide range. The difference between the findings of ESDO and those of the present studyis mainly due to the difference in contribution from the Ship Recycling Industry. ESDO's study estimated a large amount of e-waste from Ship Recycling Industry (8.86 Million Ton) which is said to be illegal import. The present study did not find any such evidences and hence its estimation is based on consideration of only the amount found during the field visit. The basis of estimation by Balde et al. (2017) could not be known, therefore it will not be fair to make any comment on their value. It can only be said that the variation of e-wastes amounts between Balde et. al (2017) and the present study is not so wide and many assumptions and approximations are involved in the estimation process, resulting in such variations.Another important factor is the availability and authenticity of data. Since there are no e-waste management system in Bangladesh and therefore there exists no database on amount of sale, consumption, recycling, export of EEE products. There are some other findings on e-wastes amount in Bangladesh (Chapter 2) but almost all of them considered one or two items (mainly mobile phones and computer), some are only for Dhaka and some are only for a specific year. Therefore, those data are not comparable to the data reviewed and analyzed under the present study.

The second estimation is based on primary data of generated e-wastes from different sources in Bangladesh (Section 4.3, Chapter 4). The total amount of e-wastes obtained from this approach is 0.0133 million ton/yr (Table 4.7).A questionnaire survey was conducted only within a small area of concentrated e-wastes businesses of Dhaka City. Therefore, it does not show the whole picture of e-wastes businesses and the exact amount of e-wastes which are undergoing recycling could not be known. Moreover, the data from all the nine licensed recyclers and exporters could not be obtained, only a few recyclers provided their data.Therefore, the amount appears (0.0133 million ton/yr) much less compared to the amount estimated (0.40 million ton in year 2018) in approach 1 (mathematical model), based on sales data. It is worthy to mention here that all the e-wastes generated in Bangladesh do not enter into the formal and informal recycling businesses. Findings from existing literature, and alsothe presentstudy show that only a small fraction of generated e-wastes enter into the recycling business and the rest end up at the landfillsites.

7.3 DISCUSSION ON ASSESSMENT OF IMPACTS OF E-WASTES

It is well established that WEEE contains many hazardous and toxic elements which cause severe adverse impacts on human health and environment (Chapter 2, Section 2.4). The present study has also found significant concentration of hazardous elements in PCBs of computers and mobile phones (Table 5.3 and Table 6.1).Although it is understood from literature review that improper handling and recycling of e-wastes may cause several diseases like cancer, neurological problem, respiratory diseases, disorder of kidney, lungs, liver, and the nervous system disorder (Table 2.11), it is very difficult and involves a complex process to prove this, specially for a developing country like Bangladesh.

To assess the impacts of e-wastes on human health, scientific and pathological test reports of blood and urine samples of people involved in e-wastes handling and recycling are required. Results of such tests can support the claim of any direct relation between e-waste and health hazard (Huo et al., 2007; Frazzoli et al., 2010).In the present study, indirect approaches were adopted to assess the impacts of e-wastes on human health, specially on the workers who are involved in activities like collection, dismantling, separation and resource recovery. Survey was conducted among the workers to assess the level of their awareness on the effects of e-wastes. It has been found from the survey that none of them are aware of the hazards and health risks pose by the improper handling of e-wastes (Chapter 5, Section 5.2.1). They reported different health problems, especially frequent workplace injuries from these activities. They do not take any safety measures during carrying out these works. It has been found from the field visits that only the workers of two licensed recyclers and one compliance ship recycling industry use gloves and safety gears in performing the tasks. The workers in informal recycling businesses work bare handed, without masks or proper shoes, and without any proper safety gears. It is found that most of the workers in the informal recycling sector are in their teens and a number of women workers work in licensed recycling factory. These two groups (women and children) are the most vulnerable ones for susceptible health problems.

The present study has undertaken another approach called ‘Risk Analysis’ to assess the impacts of e-wastes on the exposed population (workers). The goal of this analysis is to estimate the potential health risk of workers by ingestion and inhalation of contaminated water and air by toxic elements such as lead, cadmium and chromium. The relationship between the intensity of the pollutant and potential risks to human health is assessed by human health risk assessment methodology proposed by USEPA (1989). The risk analysis result shows that all age group of workers (including children and adult) are at carcinogenic and non-carcinogenic risks of health hazards through inhalation of toxic elements such as Pb, Cd and Cr (Tables 5.6-5.8, Chapter 5). Although the exposed workers’ health is not at risk through ingestion (water) of Cd and Cr, but the workers are at carcinogenic risk of health hazards due to ingestion of lead (Pb).It is noted here that due to the dearth of air quality data in the exposed working areas, concentration of Pb, Cd and Cr are considered from a study on Trace metal Concentrations in Air of Dhaka City (Islam et al., 2015). Water and soil samples were collected from the surrounding areas of the e-wastes recycling businesses and analyzed in the laboratory in the present study and used in the risk analysis through ingestion.

The present study shows that in Bangladesh, about 97% of e-wastes are ended up to landfill sites which pose a serious threat to environment. The leaching of toxic heavy metals from e-wastes in the landfill contaminate the soil and groundwater and there is a good chance of contamination of surface water by surface runoff. Atmospheric pollution due to open burning and dismantling activities pose a risk in the surrounding locality as well as in remote areas. Such an environmentalpollutionserves as a crucial source of food chain contamination that may accumulate in aquatic life such as fishes, agricultural lands and livestock.

7.4 DISCUSSION ON RESOURCE RECOVERY POTENTIAL OF E-WASTE

E-waste is often called as urban mineas it contains so many precious metals (Au, Ag, Pt, Pd, Nd etc.) along with hazardous metals. If recovery of these precious metals can be performed efficiently in an environmentally friendly way, e-waste isnolonger remains a waste, rather it turns into resources. In fact, recovery of value metals from e-wastes is more efficient than mining of value metals from ores. The present action-based research project has attempted to recover a number of value metals such as gold, silver, copper and tin from printed circuit board (PCB) of cell phones and computers and computer RAMs. The presence of different elements including the value metals are identified by XRF, SEM and AAS analysis.It is noted here that the concentration of various elements present (Table 6.1, Chapter 6) in tested PCBs/RAMs varied in a wide range and the reason behind this variation is that the contents of PCBs vary from manufacturer to manufacturer, even with the variation in model types. To recover the value metals, a series of laboratory experiments and analyses were carried out following different routes to make the recovery more efficient and successful (Chapter 6). The present study has adopted hydrometallurgy method over pyrometallurgy to recover the value metals since hydrometallurgical process has less environmental hazards, high selectivity towards individual metals, morefeasible for all metals and their alloys compared to pyrometallurgical process. The laboratory test results of value metals recovery havedemonstrated an efficient recovery of these metals (Silver >94%, Copper >99%, Tin >86%)(section 6.4.2, 6.4.3, 6.4.4, Chapter 6) and shown a promising potential of recovery of precious metals for Bangladesh. Gold recovery was performed using the latest environment friendly technique and showed significant recovery of about 600 gm per ton of waste PCB (section 6.4.1, chapter 6).

It has been found from this study that every year licensed recyclers and exporters export a significant amount of e-wastes, mainly used high-grade PCB and obsolete Telecom equipment which are rich in value metals, to developed countries like Singapore and Japan where they have facilities to recover the precious metals from these e-wastes(Table 4.7, Chapter 4).Again, a considerable amount of e-wastes is disposed of in the landfills, thus polluting the environment and wasting the resources within it.Availability of a proper e-waste management and resource recovery systemin Bangladesh could have made it possible to recover the value metals from the e-waste and add value to its economy.Given the right environment in terms of policy support, financial incentives and infrastructure facility and technology, recovery of resources from e-wastes can potentially lead to the development of a new industrial sector and thus enhance the growth of the country.

7.5 DISCUSSION ON DRAFT E-WASTE GUIDELINES

Although it was not in the ToR of this project but a point was raised during the inception workshop on May 24, 2018 for review of the e-waste management guidelines. As such, the present research has reviewed the stated E-Waste Management Guidelines (2nd draft, 2016)and has made some observations which are as follows. The draft E-Waste Management Guidelines, 2016 advocates EPR (Extended Producer Responsibility) policy to manage the e-wastes in Bangladesh. According to EPR principle, it is the manufacturer's/producer's sole responsibility to manage the product after its end of life. This EPR system is running in some developed countries such as Germany and France successfully and is a proven system to manage e-wastes.These are all developed countries and they have long running institutional mechanisms in place to implement and monitor such a policy. However, implementing similar policies in a country like Bangladesh should involve due consideration of its existing conditions, socio-economic situation, institutional capacity, implementation mechanisms and above all acceptability by the stakeholders. On a brief review, it can be said that if EPR is introduced in e-waste management in Bangladesh, the producer will pass on the additional cost of managing the wastes to the consumers.Considering the Bangladesh perspective, it is suggested that the system should not be solely based on EPR, there should be some responsibility of and oversight from local government as well to manage the e-wastes. To make the management system effective in Bangladesh, public awareness on the matter, effective collection and separation of e-wastes should be the focus of the policy. Government can offer incentives to grow recycling and processing plants and thus encourage the industrialists and entrepreneurs to come forward and make a positive contribution to the economy. It is the research team's view that before finalizing the draft, more discussion and debates on this important issue among the stakeholders should be carried out.

Chapter 8

Conclusions

8.1 CONCLUSIONS

The purposes of this study were to establish a baseline regarding the management of electrical and electronic items after their end of life (e-wastes), to assess their impacts on environment and human health and to examine the potential of value metal recovery from this waste. The major conclusions drawn from this research are as follows:

- The estimated amount of e-wastes is 0.31 million ton in 2016, 0.40 million ton in 2018 and 4.62 million ton by 2035
- The growth rate of e-waste generation per year is around 20%
- Around 0.0133 millionton e-wastes enter into the recycling businesses every year
- The worker involved in e-wastes handling, dismantling and recycling are at risk of carcinogenic and non-carcinogenic health hazards through inhalation of toxic elements such as lead, cadmium and chromium
- Workers health are at risk (carcinogenic) due to the lead poisoning through ingestion but chromium and cadmium do not pose any health risks through ingestion
- The awareness level regarding the health impacts of e-wastes among the workers is nil
- Workers, specially children in informal sector, carry out their recycling jobs without any safety measures
- Improper recycling and disposal of e-wastes pose risk to the environment. The weathering action and chemical reaction accelerate the leaching of hazardous elements from e-wastes and release those in air, water and soil and thus pose a serious threat to the environment.
- The presence of different elements including the value metals such as gold, silver, copper, tin, zinc etc. and toxic metals such as Arsenic, Mercury, Lead, Chromium from printed circuit board (PCB) of cell phones and computers and computer RAMs were identified by XRF, SEM and AAS analysis. The concentration of various elements varied in a wide range.

- Efficient recovery of silver >94%, Copper >99%, Tin >86% through hydrometallurgical processes was achieved. Gold recovery(600 gm/per ton of waste PCBs/RAMS) using latest environment friendly technique showed a promising potential of recovery of precious metals for Bangladesh.

8.2 RECOMMENDATIONS

Electronic waste is the fastest growing waste in the waste stream of modern world. With technological innovation and rapid growth in economy of Bangladesh, generation of e-wastes are growing at a fast pace and to manage this waste in an environmentally sustainable way is a big challenge for Bangladesh. Based on the research findings and discussion, following recommendations are made:

- Draft E-Waste Management Rule 2017 should be promulgated soon
- Inventory and database of e-wastes (at least for selected items) should be established
- Separate collection, processing, recycling, recovery and disposal facilities should be established for proper e-waste management
- Awareness raising campaign among the consumers (through poster, leaflets, brochure, Radio-TV advertisement) should be given priority to make collection system effective
- Draft E-Waste Management Guidelines, 2016 should be finalized with consultation with the relevant stakeholders
- Workers health and safety should be ensured in recycling process
- Government should provide incentives to the industrialists and entrepreneurs to come forward to set up recycling and recovery plant and thus enhance the sustainable development.

8.3 CONSTRAINTS AND LIMITATIONS

The research team has faced many constraints and challenges while conducting the work. Some are as follows:

- Conducting questionnaire and field survey was a big challenge for the team. The e-waste collectors, dealers, bhangari shop owners were not at all cooperative of giving information because of unknown fear, insecurity and lack of awareness
- Collection of sale/import data of EEE items was also a challenge since there exists no system of maintaining registry

- Because of dearth of data, many assumptions and approximations are considered in estimating the generation of wastes
- Due to unavailability of actual data, assessment of health risk through inhalation was based on the secondary data
- The biggest problem in the recovery of desired metal was a necessity of applying different technologies for the processing of various materials, which are extracted in the subsequent stages of recycling. Material complexity of PCBs complicated the hydrometallurgical processes and reduced the effectiveness of metals recovery in some cases.
- To the best of our knowledge, the value metal recovery experiments in the present study were performed for the first time in Bangladesh. The desired recovery has obtained after a series of laboratory experiments by trial and error method which delayed the whole recovery process.

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ANNEX A

Questionnaire Survey

Sample Questionnaire Survey for E-Waste Collectors

Interviewer's Name:	Date:
Location:	Sl No/Code.
Interviewer's Signature:	

A. Information of Respondent

1. Name:
2. Gender: Male / Female
3. Age:
4. Number of years working in this profession:
5. Working Area:
6. Working Hours per day:
7. Monthly Income:
8. Family Size:

B. Information on E-Waste Collection

(i) Please name the used **electronic items** that you collect, segregate, salvage or recycle

(ii) State the no. of units or wt of each type of e-waste that you collect and/or sell to dismantlers per month or per day

Type of E-Waste	No. of pieces/day or month	Amount in tons or kg/day or kg/month	Average wt per month
Computer accessories like RAM, hard disk etc.			
Mobile phones			
Printed circuit board of mobile phones			
Printed circuit board of computers			
Refrigerators or their components			
Televisions or their components			
CRT bulbs			
Microwave ovens or their components			
Air conditioners or their components			
Photocopiers or their components			
Sim cards of mobile phones			
Others			

(iii) Do you use any safety measures in collecting, segregating, dismantling the waste? If yes, please mention those.

(iv) Do you know that e-waste contains toxic materials? If yes, please specify.

(v) Did you suffer any illnesses since you are doing this work? If yes, please specify.

(vi) Did you have any accident or cut during working? If yes, please specify

(vii) How much money you get from selling these to the dealers? Tk/month or Taka/day

Sample Questionnaire Survey for Owner/Dealer of E-Waste Recycling Shop/Bhangari Shop

Interviewer's name:	Date:
Location:	Sl No/Code.
Interviewer's Signature:	

A. Information of Respondent

1. Name:
2. Gender: Male / Female
3. Age:
4. How long have been in this profession:
5. Location:
6. From what sources you get the used items? and how many people supply those items to your shop?

7. Please name the kind of electronics that you get and the average amount (pieces/ kg) in a month. Please mention the buying and selling prices of these items.

E-Waste Items						
Avg. wt						
Quantity purchased/month						
Buying price						
Selling price						

8. What do you do with these items? Please describe

9. Do you do any segregating, dismantling in your shop or just sell those?

10. What happens to the non-salvageable materials or discarded materials?

11. Do you know that e-waste contains toxic chemicals?

ANNEX B

Product Life Span

Table C. Assumptions for life span and EOL percentage from the total sales for all products. (Chang et al, 2015)

Product	Life Span	End of Life Percentage
Desktops	7-years	25%
	9-years	25%
	12-years	25%
	15-years	25%
Portables	3-years	20%
	5-years	20%
	6-years	30%
	7-years	30%
CRT TVs	8-years	25%
	11-years	25%
	15-years	25%
	17-years	25%
Flat TVs	9-years	80%
	10-years	10%
	11-years	10%
PC CRT Monitors	5-years	25%
	8-years	25%
	10-years	25%
	13-years	25%
PC Plat Panels	9-years	80%
	10-year	10%
	11-years	10%
Hard Copy Peripherals	4-years	25%
	7-years	25%
	9-years	25%
	14-years	25%
Keyboards	4-years	90%
	5-years	10%
Mice	3-years	90%
	4-years	10%
Projections & Monochrome	8-years	80%
	9-years	10%
	10-years	10%
Cell Phones	2-years	65%
	5-years	35%

ANNEX C

Risk Analysis Sample Calculation

Risk Analysis (Carcinogenic)

Sample Calculation-1

Assume that the Cadmium a known carcinogen, is found in air at a constant concentration of 6.29×10^{-6} mg/m^{-3}. Calculate the risk for exposure to this Cadmium for an average adult who inhales 30 m^3/day (MEI Chart) with 50% absorption for a lifetime. Cadmium slope factor is SF=6.1 (mg/kg.day)$^{-1}$ for inhalation value.

According to BBS- Average Life Expectancy for Bangladeshi= 71.6 years.

Average Body Weight= 60 kg

Exposure Duration= Avg. life expectancy= 71.6 years (for carcinogenic diseases)

Exposure Frequency = 300 days (for case W-C)

Solution:

The Intake Rate (in mg of contaminant per kg of body weight and per day)

$$\mathrm{I} = A \times \frac{C \times CR \times EF \times ED}{BW \times AT}$$

Here given,

$C = 6.29 \times 10^{-6}$ mg/m^3

$CR = 30$ m^3/day

$EF = 300$ days/year

$ED = 71.6$ years

$BW = 60$ kg

$AT = 365$ days/year

A= 0.50

$SF = 7.845 \times 10^{-7}$

$$\mathrm{I} = 0.50 \times \frac{6.29 \times 10\text{^} - 6 \times 300 \times 30 \times 71.6}{60 \times 365 \times 71.6} = 1.29 \times 10^{-6}$$

Now,

Risk, R = I × SF

$= 6.1 \times 1.29 \times 10^{-6}$

$= 7.76 \times 10^{-6}$;> 10^{-6}

Since risk exceeds 10^{-6}, therefore this is unacceptable and poses a carcinogenic health risk.

Risk Analysis (Non-Carcinogenic)

Sample Calculation-2

Estimate the ingestion intake rate for non-carcinogenic effects on an adult worker in a work place receiving tap water with an average Cadmium concentration of 0.18mg/L. What is the risk? (Oral Reference Dose Factor for Cadmium is 5×10^{-4}) (MEI Chart, USEPA)

According to BBS- Average Life Expectancy for Bangladeshi= 71.6 years.

Average Body Weight= 60 kg

Exposure Duration= 30 years (for non-carcinogenic diseases)

Exposure Frequency = 300 days (for case W-C)

Solution:

The Intake Rate (in mg of contaminant per kg of body weight and per day)

$$\mathrm{I} = \frac{C \times CR \times EF \times ED}{BW \times AT}$$

Here Given,

C = 0.18 mg/L

CR = 1 L/day

EF = 300 days/year

ED = 30 years

BW = 60 kg

AT = 365 days/year

Oral RfD = 5×10^{-4}(mg/kg.day)

$$\mathrm{I} = \frac{0.18 \times 300 \times 1 \times 30}{60 \times 365 \times 30} = 2.47 \times 10^{-3}$$

Hazard Quotient, HQ $= \frac{I}{RfD} = \frac{2.47\times10^{\wedge}-3}{5\times10^{\wedge}-4}$ = 4.94; Which is greater than 1.

Since the ratio is more than unity, therefore, this level of CadmiumisUnacceptable and poses anon-carcinogenic health risk.