India's Lethal Informal E-waste Recycling: A Case Study of Delhi and NCR Region

Athar Hussain, Sanjay Kumar Koli, Rajdeep Tripathi and Suneel Pandey

Abstract In India, there is a very less awareness about the formal recycling of electronic wastes. The recycling is taken into account informally to make profit in terms of money. The current study has been carried out in order to examine the recovery potential from residues collected from e-waste sites at Delhi NCR location. All these recycling works are done informally and unorganized manner. Informal recyclers adopt techniques such as pyro-metallurgy (using heat), hydro-metallurgy (using acid) and electro-metallurgy (using current). After extraction of precious metals, the remaining residues are not properly dumped into landfill sites. These residues are just thrown on lands without any precautions. However, in these remaining residues, still there is a quantity of precious metals that are affix. Au is one of the prime precious metals which is found to be present in satisfactory amount in all the samples of e-waste. However, of all the metals, the lowest concentration of cobalt metal has been observed, and highest concentration of copper metal has been observed in all e-waste samples of the study. The key to success in terms of e-waste management is to develop eco-design devices, properly collect e-waste, recover and recycle material by safe methods, dispose of e-waste by suitable techniques, forbid the transfer of used electronic devices to developing countries and raise awareness of the impact of e-waste. A national scheme such as EPR is a good policy in solving the growing e-waste problems.

Keywords Electronic waste · Printed circuit board · Heavy metals

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1 Introduction

Due to gigantic increment in population and advancement in technology day by day, the waste generation is surging tremendously throughout the globe. The human population is expected to reach 11.18 million by the end of 2100 (U.N. Population Division). The global waste generation rate is expected to reach 2.2 billion tons per day by 2025. In spite of having so many advanced treatment technologies available in the world, most of the waste ends up in the landfill, and it creates a major problem not as an environmental aspect but health and development aspect as well [7]. E-waste is a generic term encompassing various forms of electrical and electronic equipment (EEE) that are old, end-of-life electronic appliances and have ceased to be of any value to their owners [15]. E-waste stream is increasing by 4–5% every year [5]. E-waste is a heterogeneous mixture of materials, its composition increasing rapidly and continuously [3]. Globally, 41.8 million metric tonnes of e-waste was generated in 2014. These electronic items are the hardware part of the computer [4]. India is the fifth biggest producer of e-waste in the world discarding 1.7 million tons (MT) of electronic and electrical equipment in 2014 [6].

Apart from Moradabad (U.P.), this is one of the major sites for recycling of e-waste in North India. Huge mountains of e-waste are formed day by day because of change in lifestyle of people, GDP growth of country and using of new electronic product in the market, and this creates a huge problem in developing as well as in developed countries. Kumar et al. describe that the population does not have any relation with the e-waste production, while GDP has direct correlation with e-waste production. In developed countries, e-waste constitutes 1–2% of the total solid waste generation. The growth rate of discarded electronic waste is high in India since it has emerged as an information technology giant and further aggravated due to modernization of lifestyle. E-waste is considered to be carcinogenic and hazardous waste [10].

Informal scrap networks have historically generated income by collecting, extracting and selling recyclable materials [2]. Inappropriate disposal of e-waste led to the human and environmental damage, along with the high value of harmful component materials. In patients, ten times more lead concentration has been found in blood steams [8]. Basically, copper, silver, gold and platinum encourage e-waste material recovery, and open burning to extract metals is widely adopted [1], and heavy metals are ultimately accumulated in the roots of the soil [9]. Gold, silver and palladium can be recovered with a high level of efficiency in the refining process. Copper and precious metal smelting works are linked to the material value of the PCBs supplied. A precise analysis data is available for different types of assembled PCBs.

The physical composition of e-waste is very diverse and contains over thousands of different substances, which falls under organic and inorganic fractions. Heavy metals form a significant part of inorganic fraction accounting for 20–50% and may affect the nervous system, blood and kidney [11]. These fractions consist of hazardous metallic elements like lead, cadmium, chromium, mercury, arsenic and selenium and precious metals like silver, gold, copper and platinum. More efficient recovery systems could be developed for the conservation of precious or valuable metals from e-waste.

Considering the above mentioned-facts in view, a study was being planned in order to assess the e-waste management strategy and to incorporate all of the major parameters of e-waste recovery, their uncertainties and interactions into an analysis of recovery of useful materials components. This includes analysing available separation and recovery technologies. The major objectives of the present study have been undertaken in order to assess the material recovery situation in informal sector of recycling in Delhi NCR region. Also, evaluating the concentration of precious and other metals from residues of PCBs generated after informal processing from Delhi NCR location is also a part of the study. The framework of environmentally sound management of e-waste residue has also been included in the study.

2 Materials and Methods

2.1 Study Area

In the present study, the Delhi NCR region comprising of e-waste sites located at Tila Sahbazpur, Loni (Rajiv Nagar, Mandoli), Ghaziabad and Old Seelampur, Delhi, has been surveyed and selected for the present study. At these sites, both collection and recycling procedures have been carried out informally by unprofessional workers. It has also been informed that most of the persons involved in recycling business are migrants from Bihar ($\approx$90%). E-waste is transported from institutions and cities across the country at two main clusters of Seelampur and Mayapuri.

2.2 Sample Collection, Preparation and Analysis

Burnt and discarded PCB samples of recycled e-waste were collected from the study site. The random grab sampling technique has been used for the collection of e-waste residue samples from the site. PCBs thrown by workers were collected from sites after and processing carried out by leaching process to recover all the precious metals undertaken in the study. The seven samples were collected of burnt and discarded PCBs. Pretreatment includes several steps as oven drying, crushing from cutter, grinding through mixer, sieving and sample weighing. PCB samples were dried in the oven at a temperature about 60–70 °C for 2–4 h and crushed by cutter into smaller pieces. The samples collected from different sites were being labelled and designated as s5, s6, s7, s8, s9, s10 and s11.

All collected samples were shredded into smaller pieces converted into powdered form by grinding through mixer. After grinding, the samples were passed through 60 mm size sieve. The analysis and testing of all the samples were being carried out in triplicate, and after digestion, 100 mL of each sample was collected for further study. The metal concentration has been determined using atomic absorption spectrophotometer (AAS). The analysis and stepwise calculations of the obtained results in the present study are shown in Fig. 1.

The stepwise calculations are as:

(i) Metal in new PCB (g/kg of PCB) (A)
(ii) Metal in PCB after copper (Cu) recovery (g/kg of PCB) (B)
(iii) Metal discarded in environment (g/kg of PCB) (C)

Metal recovered in the second phase after the first phase of copper (Cu) removal has been calculated as PCB $(\%) = \frac{A-B}{A} \times 100$. Similarly, metal recovered in the third phase as compared to phase I after being burnt and discarded has been calculated using equation PCB $(\%) = \frac{A-C}{A} \times 100$

2.3 *E-waste Survey on Selected Sites of Delhi/NCR*

The information technology (IT) industries and related organizations have expanded electronics marketing in Delhi and its NCR regions broadly over the past few years. The constant upgradation of software has reduced the lifespan of personal computers (PCs) to about ten years [12]. As a result, a large number PCs are auctioned in Delhi. E-waste generated over years is algebraically directly proportional to the growth of IT companies in the city. Delhi produces about 9.5% of total e-waste generated in India. Delhi is the second largest city generating e-waste in India after Bangalore [13]. Besides the computer assembly hub operating in the city, the traders also receive huge quantities of PCs from different parts of country.

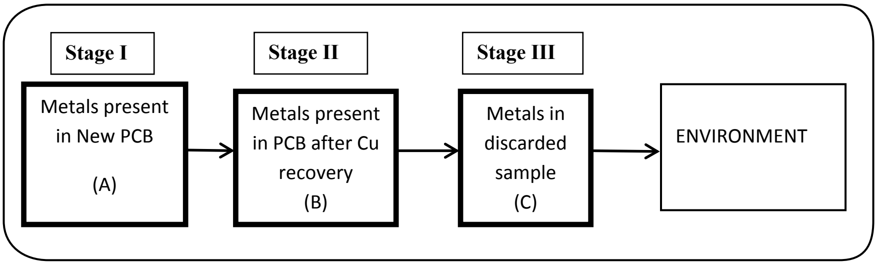

Fig. 1 Stepwise calculation for recovery rates of metals from PCB samples

Scrap dealers sell certain components like PCBs and integrated circuits (IC) directly to dismantlers for dismantling. Although, there are many sites at major locations in Delhi/NCR where e-waste get recycled and material recovery is done. The major e-waste generating sites undertaken in the present study have been discussed and surveyed accordingly.

3 Results and Discussions

The analysis of collected samples of gold and zinc has been carried out, and the result has been summarized in Table 2 and in Fig. 2. From Fig. 2, it can be observed that the maximum Au has been recovered from s11 as compared to the minimum value of sample from site s5.

Gold (Au) is a noble metal and highly precious in nature. It has high quantity of PCBs from e-waste. The highest Au concentration of 46.19 mg/L has been observed in sample s11. However, mean concentration of 32.4 mg/L Au has been observed in all the samples of the present study. Zinc (Zn) metal is most commonly used as an anticorrosion agent. A widely used alloy that contains zinc in brass, where copper is alloyed with from 3 to 45% zinc, depending upon the type of brass is to be manufactured. In the present study, the concentration of Zn in all samples ranges from 18 to 74 mg/L. The present investigation has also been carried out in order to determine the concentration of valuable metals present in the e-waste (Fig. 3).

An attempt on recovery potential of valuable metals in collected seven samples (PCB) from the Loni site of NCR region has also been undertaken in the present study. Samples are categorized into three categories comprising of sample number s5, s6, s7, s8, s11 as PCBs while sample number s9 as discarded and burnt after informal recovery of metals on site and sample number s10 having new PCB

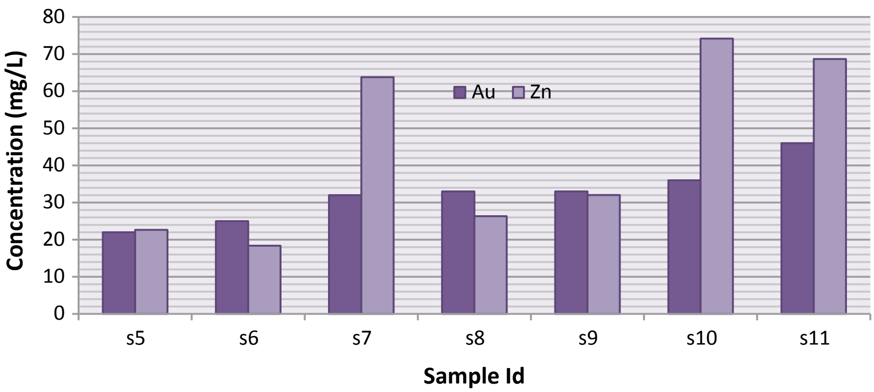

Fig. 2 Concentration of Au and Zn in samples from different locations of study area

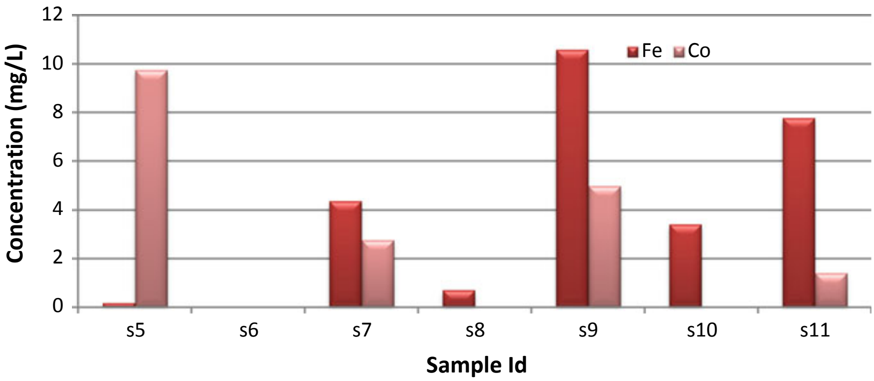

Fig. 3 Concentration of Fe and Co in samples from different locations of study area

Table 1 Metals concentration in e-waste as analysed in the present study

Sample id	Concentration (mg/L)									
	Ag	Al	Au	Fe	Cr	Ni	Pb	Zn	Co	Cu
s5	636	16,950	22	0.19	111	13	1465	22	9.76	1096
s6	746	321	25	0	11	30	713	18	0	2179
s7	6523	13,112	32	4.39	107	157	2175	63	2.78	2940
s8	791	280	33	0.72	8.86	16	679	26	0	2112
s9	16	16,899	33	10.6	547	21	782	32	5.01	34.5
s10	37	5110	36	3.43	113	51	2099	74	0	19
s11	29	10,671	46	7.78	297	14	377	68	1.42	2383
Average	1254	9049	32	3.87	170	43	1184	43	2.71	1538

collected and PCB after Cu recovery as summarized in Table 1. Ferrous concentration has also been observed in all the e-waste samples. The concentration of Fe in sample s6 has been observed below the detection level (bdl) in the present study. However, the mean concentration of all the samples in the present study has been observed to be 4.52 mg/L. The highest concentration of 10.64 mg/L has been observed in sample s9. Most part of the produced cobalt is utilized in preparing alloys and is used in different areas in manufacturing of electronic equipments.

Therefore, the produced cobalt is consumed in most of the alloys being produced. The foremost application of cobalt is as the free metal, in production of certain high-performance alloys. However, in the present study, the concentration of cobalt in most of the samples has been found to be below the detection limit. The maximum cobalt concentration has been observed in sample s9. Silver (Ag) is another major precious metal that has also been analysed in the present study. The average concentration of silver in all the samples has been observed to be 415.35 mg/L. However, it has also been observed that Ag can be recovered on large

Table 2 Metals concentration (g/kg) from e-waste as per category of PCB

Metals (g/kg)	New PCB collected (phase I)	PCB after Cu recovery (phase II)	PCBs discarded and burnt after informal recovery (phase III)
Ag	0.016	0.037	0.482
Al	16.90	5.110	7.740
Au	0.03	0.036	0.032
Fe	0.01	0.003	0.003
Cr	0.55	0.112	0.108
Ni	0.02	0.051	0.047
Pb	0.78	2.099	1.818
Zn	0.03	0.074	0.046
Co	0.01	0.00	4.653
Cu	0.03	0.019	1.788

scale from e-waste. The maximum aluminium (Al) concentration of 16,950 mg/L has been observed in the sample s5 taken in the present study. However, the maximum gold (Au) concentration of 46 mg/L has been assessed in sample s11 in the present study. Au is one of the prime precious metals that is found to be present in satisfactory amount in all the samples of e-waste. The highest chromium (Cr) concentration of 297 mg/L has been observed in the sample s10 of the study area.

The average concentration of 170 mg/L of chromium has been assessed in all samples of the study area. Nickel (Ni) is another important metal generally used for electroplating and metal coating by most of the metal manufacturing industries. The highest concentration of 157 mg/L of Ni has been observed in sample s7 as compared to all other samples. Lead (pb) is another important metal which is toxic heavy metal and can be recovered 100% if proper recovery method is applied. The highest Pb concentration of 2175 mg/L has been observed in sample s7 in the present study. However, the average lead concentration of 1670 mg/L has been found in all samples. The highest zinc (Zn) concentration of 74 mg/L has been observed in sample s10 of the study area. However, of all the metals, the lowest concentration of cobalt metal has been observed, and highest concentration of copper metal has been observed in all the e-waste samples of the study.

The load-based metal concentration at phase I, phase II and phase III from PCB samples has been determined and summarized in Table 3. In phase I, the maximum concentration of aluminium has been found to be 16.9 g/kg, and minimum concentration in phase I has been found to be 0.01 g/kg of metals Fe and Co. In phase II, the maximum Al metal concentration of 5.11 g/kg is observed, and no Co metal is detected in the phase II of the study. However, the maximum AL metal concentration of 7.74 g/kg has been observed, while minimum concentration of 0.003 g/kg of Fe is detected in phase III of study. The precious metals Ag and Au have also been recovered in all the phases of the study. The Au concentration of 0.03, 0.036 and 0.032 g/kg has been obtained in phase I, II and III of the study,

Table 3 Concentration of metals in all the samples analysed in the present study

Category	Sample id	Concentration (mg/L)									
		Ag	Al	Au	Fe	Cr	Ni	Pb	Zn	Co	Cu
Discarded and burnt PCBs	s5r1	665.31	17,637.5	25.31	0.06	117.37	13.12	1579.94	28.35	13.04	1218.81
	s5r2	579.23	16,735.7	22.46	bdl	109.92	14.46	1413.68	19.47	13.63	1032.19
	s5r3	661.99	16,475.9	16.91	0.32	8.89	11.72	1401.14	20.09	2.61	1037.31
	s6r1	712.89	282.2	19.53	bdl	10.38	30.97	719.83	20.01	bdl	2277.95
	s6r2	758.29	371.4	25.51	bdl	13.96	31.99	702.61	17.17	bdl	2206.54
	s6r3	765.71	308.8	28.94	bdl	98.67	27.67	717.32	17.97	bdl	2051.03
	s7r1	563.67	13,811.1	29.86	3.62	112.79	139.41	2098.75	59.84	bdl	3081.46
	s7r2	756.55	12,710.1	33.17	4.31	109.58	182.92	2204.39	58.32	bdl	2961.89
	s7r3	637.86	12,813.9	32.94	5.26	6.34	148.04	2221.88	73.23	2.78	2777.09
	s8r1	909.08	255.6	31.53	0.55	10.73	18.01	730.97	29.35	bdl	2112.61
	s8r2	627.82	267.8	32.83	0.99	9.52	13.61	646.84	25.33	bdl	1820.28
	s8r3	837.33	317.1	34.06	0.62	534.40	17.74	658.61	24.29	bdl	2401.64
New PCBs	s9r1	14.80	16,635.8	32.25	10.35	564.23	17.23	790.19	30.34	4.40	46.41
	s9r2	16.87	16,852.7	33.90	11.13	541.40	24.42	816.04	32.90	4.68	33.54
	s9r3	17.11	17,207.3	33.50	10.44	113.78	22.14	740.50	32.81	5.96	23.20
PCB after Cu recovery	s10r1	36.24	5128.7	33.33	3.09	102.17	76.97	2246.09	66.86	bdl	26.62
	s10r2	37.12	5203.4	35.06	2.84	120.85	30.86	2109.75	91.55	bdl	12.39
	s10r3	36.74	4997.0	40.69	4.36	328.73	44.09	1941.88	64.11	bdl	16.66
Discarded and burnt PCBs	s11r1	33.37	11,167.0	47.84	8.24	258.79	13.13	3229.51	72.45	bdl	2550.88
	s11r2	28.84	9988.8	45.74	7.46	302.54	15.25	4641.54	67.88	1.82	2448.24
	s11r3	25.63	10,859.0	44.99	7.63		14.24	3458.82	65.64	1.03	2149.96

respectively. However, the concentration of Ag has been found to be 0.016, 0.037 and 0.482 g/kg in phase I, II and III of the present study, respectively. However, in phase III, when PCBs are discarded and burnt after informal recycling, the maximum and minimum concentration of Al and Fe was observed as 7.74 and 0.003 g/kg in the e-waste samples (Table 2).

3.1 E-waste Situation at Major Sites in Delhi/NCR

3.1.1 Loni Study Area

Motherboards are processed at unconfined industrial area of Mandoli at a place called Tila. The area is owned by local landholders, and they give their land on rent to the recyclers. Dismantling and refurbishment of e-waste take place at five locations in Delhi as Shastri Park, Seelampur, Turkmangate, Mustafabad and Mayapuri. These cluster organizations tender and collect e-waste. Workers undertake testing of the collected materials, and if found suitable, the same is sent for refurbishment, and if they are not economically refurbishable, the same is sent for extracting metals and other valuable components. Materials that are recovered include ABS plastic, motherboard, tin, picture tube (99% refurbished), silver and gold. Also, it has been reported that the recycling efficiency is low due to unavailability of proper technology and remains only in extent of 30–40%. Wires are being burnt to take metal out of wires. There is no proper system and management for collected e-waste. Moreover, based on survey at site, the recyclers in Loni buy @ 400/kg and extract about Rs. 900/kg else there shall be no feasibility to run e-waste recycling business.

3.1.2 Old Seelampur Study Area

Trucks carrying e-waste unload the waste at site from 4 am–12 pm. The cluster is almost 20 years old. There are about 300 traders working in old Seelampur cluster. These traders buy e-waste and sell the same to the processors of the waste for recovering metals which have immediate monitory value. The tubes from the monitors are sometimes usable and used to make televisions. Unlike old Seelampur, Mayapuri cluster deals more in waste of electric motors. The e-waste collected includes as computer boards (Rs. 40–200 per kg), CFL (Rs. 50 per kg), chargers, fan motors, wires, cooler kits, monitors (Rs. 500–1000 per PC) and batteries, cameras, etc. Waste is bought to these traders in PVC bags and usually also common types of waste per bag. The mode of transportation is railways, trucks and transport systems on sharing basis. Waste from institutions and also even the e-waste collected from recognized recyclers many a time are sold among these traders for processing. The rates of e-waste fluctuate as market rates of metals vary. The most expensive e-waste is motherboard of computers which even has recoverable gold in it. The turnover of an e-waste trader has been informed as 5 tonnes per month, and economically, it is found varying from Rs. 18,000 per month to more than Rs. 500,000 per month.

3.2 Major Observations at E-waste Generation Sites of Study Area

3.2.1 Loni Site

Cluster has recycling units for rubber (tyres, shoe sole, etc.). The cluster also has recycling unit of glass and produces thread for flying kites (Manja). Some small workshops heat the motherboard of PCs, computer and other electronic instruments by using a domestic LPG cylinder. The varying components are removed. Motherboards after removing components still have metals. These boards are bought, stacked and open burned. Upon cooling, the metals like copper, iron and brass are segregated manually by cheap labour. It has also been observed that these motherboards are burnt during night hours (maybe to avoid attention of authorities). Acid used for recovering after use is dumped on ground without any treatment. The motherboards after all the possible recovery are also dumped randomly at convenient locations in a haphazard manner. Parts like resistors and capacitors are handled by other kinds of recyclers. These parts are first grinded and then heated at very high temperature to get rid of the plastics. The metals then secured are copper, aluminium, iron and brass. These pieces of metals are sorted through hand picking, sieving and magnets. Recyclers specialize in recycling of different parts of motherboard. Motherboards are heated to remove parts like resistors, capacitors, etc.

3.2.2 Old Seelampur Site

No specific land or cluster is allotted by the government to the site. No facilities, campaigning and awareness are initiated by the government to improvise the e-waste management process. It is also observed that there are lakhs of people who are employed through this business, and these are mostly labour class.

4 E-waste Recovery at Sites of Study Area

4.1 Loni Site

Material recovery in recycling units is highly generic and rudimentary in nature. The workers work in closed dingy areas. They handle acid, caustic solution and other health hazardous chemicals. The workers are thus exposed to several toxic elements. Further, on oversight at site of Loni, it is investigated that motherboards from expensive equipment like magnetic resonance imaging (MRI) and CT scan machines have high quantities of precious materials. These motherboards are not processed in India but are sent to a company in Belgium. It is claimed that the company can recover 98% of the precious metals from the motherboards. According to site workers, 18 tons of motherboard, 2.5 kg of gold (24 carat), 170 kg of silver and 1.75 kg of platinum are recovered. On an average, each kg of motherboard contains three pieces, which is sold the Belgian company at Rs. 5000–6000.

4.2 Old Seelampur Site

The e-waste collected is directed to the informal recovery sites where expensive metals like gold, silver, copper, brass, aluminium and shoulder are recovered from the waste. The unrecovered materials from the e-waste such as mica boards and IC parts land up in dump sites after processing. The informal trading and recovery sites are located around residential areas. Thus, the recyclers face issues with the area and money issues. The informal recyclers need recognition from the government apart from allotment of space and basic technology to safely recover material.

4.3 E-waste Recycling

Based on the latest demonstration, eco-friendly procedures such as biotechnological approaches which seem to be a valuable tool for recovery of precise metals (gold, silver and platinum) are observed. The presence and restoration of precious metals in electronic waste even in small quantities such as gold and silver influence more than 50% of the economic value of recycling business. The PCBs in the present study have been recovered by using simple mechanical and chemical procedures. Density and magnetic separation method have been used in order to collect, disassemble, pulverization and separation of PCBs. However, in the present study, 98.82% purity of $CuSO_4$ hydrate and $Al_2(SO_4)_3$ hydrates were recovered from the PCBs by using the chemical recycling method.

The scrap dealers generally adapt an environmentally friendly dismantling technique in order to recover valuable materials and to minimize the adverse effects of hazardous materials contained in CRT and PCB’s scrap. Therefore, the useful and hazardous materials can be manually separated and recovered by using this eco-friendly dismantling process. Thereafter, the retrieved materials are sent for particular treatment facilities accordingly depending upon the characteristics of that particular material.

Furthermore, from recycling of printed circuit boards for the recovery of valuable materials, the effective use of high-temperature pyrolysis is accrued out. However, silver, gold, palladium and platinum are the recovered precious metals present in waste PCBs having a clear tendency to form solutions with the main metallic constituents of waste PCBs, namely copper, tin and lead. The effective concentration has been observed due to the high affinity between copper and these precious metals. Also, a small percentage of 5–20% of valuable metals has been detected in the nonmetallic part after heat treatments in the temperature range of 800–135 °C.

5 Conclusion

As per the experimental work carried out in the present study, it has been observed that recovery rate of copper metal in phase II is estimated to be 46% by weight of e-waste as compared to phase I. Moreover, recovery rate of aluminium, gold, iron and chromium from PCBs (after burnt and discarded in phase III) has been found to be 54.19%, 2.89%, 68.96% and 80.3% by weight, respectively, as compared to phase I. Due to rapid growth of informal sector recycling, recovery or extraction of reusable components like as ceramics, polymers and metals from PCBs is processed in informal sector of Delhi NCR. However, the challenge is to adopt efficient process with maximum recovery of materials and minimal loss. The local people are suffering from health concerns as nitrogen dioxide (NO_2) and mercury (Hg) fumes might be hazard to workers since it can damage the respiratory systems. The threats recognized on e-waste recovery sites are the produced fumes while recovery process, untreated effluent and dumped solid waste. Hence, there should be a proper management and precaution systems for safety of labours at e-waste recycling sites.

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