Chemical footprint of open dumping sites due to electronic and battery waste

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Abstract: Leachate from open dumping sites is found to be a major threat towards carcinogenic chemical footprint. The present study was conducted to evaluate the supply of various chemicals from electronic and battery (E&B) waste in dumping sites. Various types of E&B waste from household sources are regularly mixed with municipal solid waste (MSW). This study reports the presence of various types of primary and secondary pollutants in MSW from E&B waste. The major organic compounds found in the leachate were various phthalates, pyrrolidone and succinimide derivatives which may be due to the presence of e-toys and battery waste in the landfill. Intrusion of leachate containing these toxic compounds into river and groundwater systems leads to health implications like reproductive and developmental disorders, endocrine disruption and even cancer. It is concluded that a proper E&B waste management is necessary to ensure human and ecological health.

Introduction: Electronic toys and batteries (E&B) are commonly used in every household and due to some bad practices and limitations in the municipal segregation system, dumped in municipal solid waste (MSW). E&B waste contains a variety of organic and inorganic pollutants, causing various health implications (Table 1) like carcinogenesis, reproductive and developmental disorders, mutagens, endocrine disruptors, neurotoxins, etc. This position is made worse in case of open dumping in the hilly regions, where leachate from open dumps is carried by various seasonal rivers and ultimately supplies various contaminants to the river and groundwater bodies [1].

E&B waste has been reported to be a cause of many disorders like childhood lymphoma [2], neurotoxicity [3], bioaccumulation [4], possible respiratory disorders [5], etc. E&B waste contains various POPs, PCBs, PBDEs, PAHs, heavy metals, toxic additives, etc. which are detrimental for environmental and public health [6,7]. E&B is responsible behind the leaching of inorganic contaminants like heavy metals such as Pb, Cr, Mn, Fe, Co, Ni, Cu, and Cd [8], and organic contaminants like phthalates [9], etc. The above pollutants may increase the risk of cancer to mankind if not managed properly [10,11]. E-waste contains

Table 1: Toxic substances present in E&B waste

Toxic substance	Presence in e-waste	Health impacts
As	LEDs, solar cells, photovoltaic devices, trace contaminant or impurity in components like semiconductors, circuit boards, displays	Carcinogen, skin lesions, cardiovascular diseases, respiratory problems, neurological disorders
Azo dyes	E-toys	Mutagenic, toxic
Ba	CRTs, X-ray tubes, semiconductors, ceramic capacitors	Gastrointestinal effects, cardiovascular effects, respiratory effects, neurological effects, renal effects, developmental effects
Be	Beryllium-copper alloys, connectors, springs, switches, and electrical contacts, X-ray windows and detectors, beryllium oxide (BeO) ceramics, electrical insulation, beryllium-aluminum alloys, semiconductors, microelectronic packaging	Carcinogen, acute and chronic beryllium diseases, skin sensitization
Bisphenol A	Plastic casings, e-toys, epoxy resins, PCBs, cables, wiring	Endocrine disruptor, immuno-suppressant downregulate antioxidant genes, genotoxic, cytotoxic
Cd	Ni-cad batteries used in cordless power tools, camcorders, household appliances,etc., conductors in electronics, pigments in paints and coatings, stabilizers in plastics, electroplating of steel, iron, and copper	Kidney damage, bone damage, respiratory effects, carcinogenic, cardiovascular effect, reproductive and developmental effect
Co	Lithium-ion batteries, magnets, alloys, plating, semiconductors	Carcinogenic, reproductive and developmental effects, respiratory effects (irritation, coughing, wheezing, shortness of breath, and chest tightness), skin irritation, cardiovascular effects, hematological effects, neurological effects,thyroid dysfunction
Cr	HDD, chromium plating, sensors and detectors	Respiratory Effects, skin irritation, cancer risk, systemic toxicity
Cu	Excellent electrical conductivity and corrosion resistance, used in PCBs, wiring and cables, connectors and terminals, coils and inductors, electomangentic shielding	Gastrointestinal distress, liver damage, neurological effects, kidney damage, hemolytic anemia, hepatic encephalopathy
Fe	Structural component, wiring, connectors, transformers inductors, magnet, storage media, for thermal management	Gastrointestinal symptoms (like nausea, vomiting, abdominal pain, and diarrhea) , organ damage, hemochromatosis, iron poisoning, hemolytic anemia
Flame retardants (BFR)	E-toys, plastic casings, PCBs, cables, wiring	Endocrine, neurological, reproductive, immune and cardiovascular systems
Hg	CFLs, batteries, thermostats, electrical switches and relays	Neurological effects, cardiovascular effects, renal effects, developmental effects, reproductive effects, immune system effects, dermatological effects
Li	Li-ion batteries, ceramics and glasses production for electronic displays, touch screens, and other electronic components	Gastrointestinal Symptoms, neurological effects, cardiovascular effects, renal effects, thyroid dysfunction, interference with nucleic acids synthesis
Mn	Magnets, ceramics, semiconductors, batteries, capacitors, plating and surface treatments	Behavioral and cognitive effects, neurological effects, reproductive and

		developmental effects, respiratory effects, hepatic effects, cardiovascular effects, impaired iron absorption
Ni	Batteries (Ni-Cd, NiMH, LIB), electroplating, magnetic alloys, connectors and terminals, PCBs, Thermal Conductors	Carcinogenic, allergic contact dermatitis, asthma, lung damage, systemic effects, reproductive and developmental effects, hypersensitivity reactions
N-methyl-2-pyrrolidone	Lithium-ion batteries, paint and coatings	Irritant (skin, eyes, respiratory system), potentially carcinogenic, affect CNS, reproductive toxicity, developmental toxicity, hepatotoxic, nephrotoxic
PAHs	Plastics, coatings and adhesives, rubber, combustion byproduct	Alters immunological responses, diarrhea, inflammation, affected the intestinal epithelium, transformation of microfold cell (M cell), carcinogenic risk, respiratory effects, cardiovascular effects, reproductive and developmental effects, immune system effects, neurological effects, skin effects
Pb	Soldering electronic components, lead acid batteries, paint, PCBs, CRTs, lead weights in electronics	Neurological effects, developmental effects, hematological effects, renal effects, cardiovascular effects, gastrointestinal effects, reproductive effects, skeletal effects
PBDEs (Polybrominated diphenyl ethers)	PCBs, plastic casings, connectors and components, cables and wiring	Carcinogen, neurotoxin, reproductive toxin, endocrine disruptor, developmental toxin, effects on immune system
PCBs (Polychlorinated Biphenyls)	Capacitors, transformers, insulating fluids, flame retardants	Carcinogenic, neurotoxic, reproductive toxin, endocrine disruption, immune system effects, lung damage
Phthalates	E-toys, cables, wiring, plastic casings and housings, packaging materials, adhesives, sealants	Reproductive and developmental disorders, endocrine disruption, liver damage, kidney damage, metabolic disorders, neurotoxicity, asthma, allergies
PVC	Insulation, wiring, cable conduits and ducts, electronic enclosures, housings, PCBs, antistatic packaging, heat shrink tubing, seals, gaskets	Brain cancer, hormonal imbalances, reproductive and developmental problems, allergies in children, hardening of connective tissue throughout the body
Se	Photovoltaic cells, photocopying, printing, rectifiers, semiconductors, photovoltaic detectors, X-ray imaging	Selenosis, cancer risk, gastrointestinal disturbances, skin and hair problems, neurological symptoms, respiratory distress, hypersensitivity reactions, impaired thyroid function
Styrene butadiene rubber	Lithium-ion batteries, adhesives, sealants, rubber components, cable insulation, protective coatings	Irritant (skin, eyes, respiratory system), potentially carcinogenic, adverse reproductive and developmental effects
REE	Permanent magnets, fluorescent lighting, led lighting, catalysts, glass and ceramics, batteries (Ni-MH, EV-LIBs)	Radioactive contamination, gastrointestinal disorders, organ damage, developmental abnormalities

over 1000 potentially toxic substances which are of serious environmental and public health concern when disposed [6]. E-waste has been recognised as the major component of MSW lately [6]. India is receiving scrap gadgets from western nations13 and stood fourth in global e-waste generation [12]. Supplementary to the generation rate, India also receives scrap gadgets from western nations [13].

E&B waste recycling is quite challenging due to complex dismantling and structure, heterogeneity of waste, material diversity, resource recovery challenges, collection and sorting challenges, lack of proper infrastructure, limited public awareness and involvement, etc. [12,14]. Exposure to the e-waste toxins regularly result in poor health and unsafe environment for the workers. Various studies confirm that the indigestion, inhalation and dermal contact with these toxins during E&B waste handling by the informal sector gives rise to occupational hazards which include cellular toxicity by heavy metals, DNA mutations, tumorigenesis, impaired cognition in children, asthma, lung dysfunction, immune dysfunction, altered cell expression, liver and kidney damage, cancer, etc. Generation of E&B waste is increasing day by day, hence investigation on the health and environmental effects of E&B waste is the need of the hour. This paper reports various pollutants from the above type of waste with a policy recommendation so that a proper 3R (reduce, reuse and recycle) can be developed with requisite government partnership.

Material and methods: Samples of leachate were collected from Kangra open landfill site. Kangra is a municipality situated in Kangra district in the Indian state of Himachal Pradesh. It is located at 32°06′11″N 76°16′24″E. The landfill site is situated at a height from where precipitation mixes with the leachate and carries the contaminants downhill to the seasonal rivers.

Leachate samples were collected, stored in cooler boxes at 4°C and analyzed within 24 hours. pH, Electrical Conductivity (EC), Ultraviolet-Visible (UV-Vis) and Fourier Transform InfraRed (FTIR) analysis were performed. pH was calculate using a digital pH meter and EC by using CDM210 conductivity meter. UV-Vis analysis was done using a UDB650 red tide spectrometer with a wavelength range between 200-800 nm. FTIR spectrometry was performed using Bruker alpha instrument with an absorption band ranging between 400 to 4000 cm^{-1}. For UV-Vis analysis, sample dilution was performed with Type-1 water. Samples with 10, 50, 100, 500 and 1000 times dilution were analyzed and best result was obtained at 100 times dilution.

Results and discussion: pH of the leachate samples ranged from 7.5-8.5 and EC readings were between 4.5-8 mS cm^{-1}. UV-Vis analysis showed an absorbance range between 200-300 nm while FTIR showed absorbance bands between 3500-2800 and 1750-700 cm^{-1}. The result confirmed the presence of CH aromatic group, C=O group, C=C group, CH aliphatic bending group, O-H group, C-N bond in the leachate samples [15]. Evidence of a variety of possible compounds were found, among them, presence of various phthalates and pyrrolidone derivatives in the samples were selected to depict the source of the contaminants in the leachate to the presence of e-toys and battery waste in the landfill. These compounds also show their presence in other e-wastes like circuit boards, semiconductors, insulating materials, cable insulation, gaskets, seals, wiring, etc.

Compounds found in the leachate reasonably consist of phthalic acid derivatives which can be identified by the presence of UV and IR peaks around 225-228 nm and 3000, 1750 and 1300 cm^{-1} [16] respectively (Figure 1 and 2), suspected for the presence of phthalates in the leachate. Phthalates are widely used in a variety of plastic products as plasticizers and can cause reproductive and developmental disorders, endocrine disruption, liver damage, kidney damage, metabolic disorders, neurotoxicity,

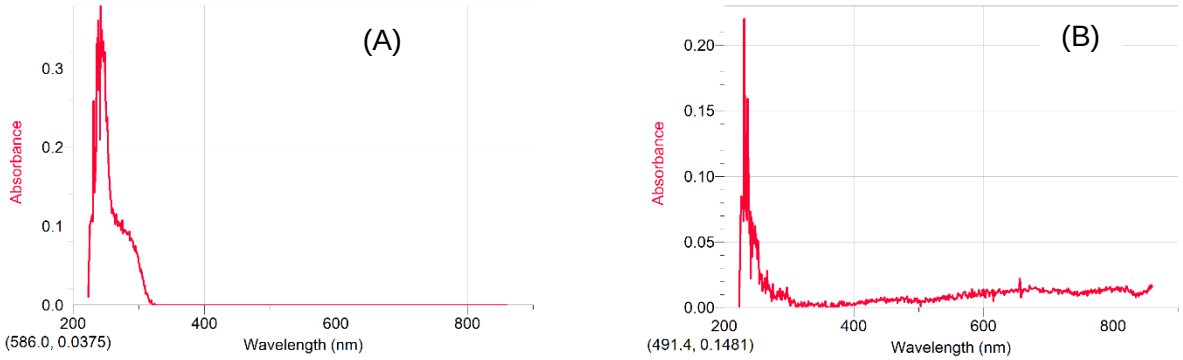

Figure 1: UV-Vis absorbance vs wavelength graph of leachate sample (A) at 100 times dilution; (B) at 500 times dilution

asthma, allergies, etc. These readily leach into the water systems and show common occurrence in wastewater, landfill leachates and groundwater. The source of these compounds in the leachate was traced to the possible presence of e-toys in the waste site.

Compounds succinimide and pyrrolidones derivatives in the leachate can be identified due to the presence of characteristic UV-Vis bands below 450 nm [17] and in the leachate sample identifies, between 230-240 nm and IR absorption bands around 1700, 1300-1400 cm^{-1} [18] (Figure 1 and 2). N-methyl pyrrolidone (NMP) is used as a solvent in paints and electronics industry. It is also used as a solvent in lithium-ion batteries (LIB). NMP is an irritant, potentially carcinogenic, reproductive toxin, developmental toxin, hepatotoxin, nephrotoxin and affects the CNS. The source of pyrrolidones in the leachate was traced to the possible presence of LIB waste in the dumping site.

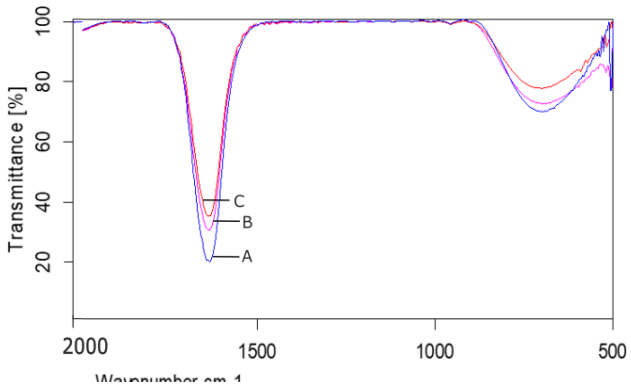

Figure 2: FTIR analysis of leachate samples A, B and C

Policy recommendation: Although the e-waste and battery waste management rules of India include aspects for the solution of E&B waste problems like the development of inventory by record maintenance at the end of every manufacturer, producer, refurbisher and recycler, collection of e-waste, labor safety monitoring, encouragement to put up facilities, public awareness and EPR, the rules require more stringent measures for their proper implementation as a lot of work is still lacking. Despite the E-waste management rules, which support recyclers and refurbishers, the number of registered recyclers are still very less. There are a total of 569 registered recyclers nation-wide as on 08-06-2023 as reported by the CPCB. This task will only work through a stronger partnership with the informal sector as they have a widespread network and have an easier channel for collection. Besides, 90% of collection and 70% of recycling is handled by them [19]. Consumer engagement in proper E&B waste management is also very less due to the lack of awareness.

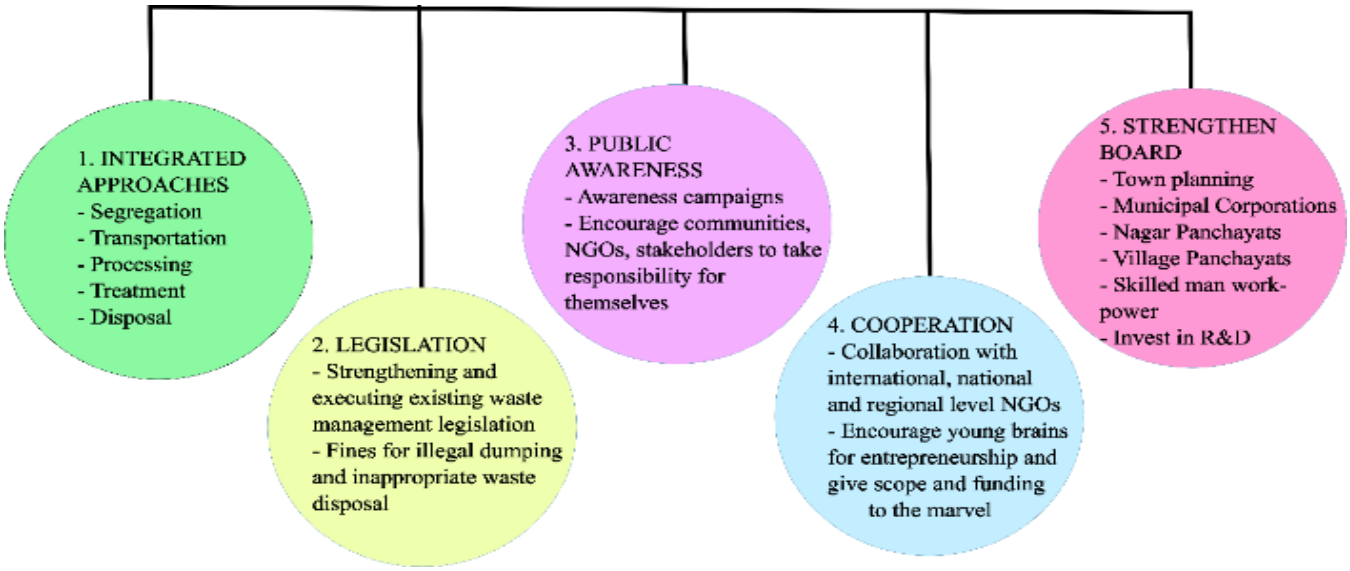

Figure 3. Waste management goals and approach

The government should provide policy incentives and awareness campaigns to promote effective management of E&B waste among the public. E&B waste often ends up in disposal sites without undergoing crucial treatment and is disposed off on open land without proper safety or environmental controls in the small towns. Additionally, burning E&B waste in open areas is also an issue of concern as it releases many toxic formulations, which are of concern to human health. To address these issues, it is essential to implement management rules for waste collection through segregation, transport, processing, treatment, and disposal procedures more stringently. The government should engage with local people and stakeholders respectfully and collaboratively to consider their participation and the role of communities in the waste management phenomenon. However, inadequate infrastructure for proper disposal sites, lack of adequate disposal facilities, and lack of skilled man workpower in India, makes this process very tedious. Therefore, State governments must strengthen town planning commissions, municipal corporations, and Nagar Panchayats to improve waste management practices (Figure 3). They should also continuously evaluate the waste management mechanisms employed at regional scales by the concerned authorities.

Conclusion: This study was conducted to detect the sources of various toxic compounds present in the leachate of an open dumping site. The analysis of compounds showed their possible source to be from e-toys and battery waste which was mixed with other solid waste. Compounds found in the leachate are detrimental to human health and ecological health and most of them are possible carcinogens. Proper awareness, management and disposal of E&B waste is hence necessary, considering their toxic nature. Public awareness and participation in WEEE waste is also required.

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