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The impact of electronic-electrical waste on human health and environment: A systematic literature review

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Sub-Saharan Africa has become one of the leading destinations for used equipment or Electronic-Electrical waste (e-waste-or-EEW) from developed economies, making its management more urgent than ever. Most studies have articulated the serious impact of e-waste disposal to the environment and public human health. Little attention or consideration has been devoted to the management of e-waste in Uganda despite the existence of laws, policies, and guidelines. Comparatively, much more attention has been paid on the disposal of plastics. In this study, using systematic literature review (SLR), the effect of irresponsible e-waste recycling and disposal on the environment and human health were amplified. Initially, articles were retrieved from four electronic databases using keywords on the environmental and health impact of e-waste and zeroed on only Google scholar and Science Direct because they constituted over 90 percent of the identified articles. Consequently, 35 papers were selected and analyzed from 8,319 papers that were assessed for eligibility to address the research questions. The SLR revealed plausible results associated with irresponsible disposal and exposure to e-waste. Specifically, the outcomes include premature births, abortions, damage to the kidney, the nervous and blood systems, skin diseases, lung cancer, respiratory disorders, and chronic brain damage. Toxic elements are detrimental to the environment since they affect the food system and water systems. Consequently, practical and technological solutions were provided and recommendations to minimize future catastrophe from e-waste to policymakers, theoretical contributions and prospects for future research were made.

Key words: Health, environment, electronic waste, technological solutions.

INTRODUCTION

In this study, a comprehensive impact of E-waste was provided to the environment and human health based on systematic literature review (SLR). Practical and technological solutions and recommendations to minimize future catastrophes from E-waste to policymakers, theoretical contributions and prospects for future research were also provided.

Discarded electrical electronic equipment (DEEE) and components, known collectively as Electronic-Electrical Waste (E-waste or EEW), are the most rapidly increasing sources of waste worldwide (Lundgren, 2012). E-waste are components destined for re-use, re-sale, salvage or

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disposal and generated from information technology (IT) telecommunication equipment and consumer electronic products. These include refrigerators, washing machines, computers and their accessories, mobile phones and chargers, batteries amongst others. Masoom and Toufique (2016) and Kozlan (2010) state that e-waste comprises all electrical and electronic products or equipment that have batteries and the power plug(s), that may become obsolete as a result of advancements in technology, status, regular tuning in style and fashion, and looming life expiration of products' usefulness. E-waste is also composed of a mixture of metals, particularly copper, aluminium and iron attached to, covered with or mixed with various types of plastics and ceramics (Oldenkotte et al., 2019).

The abundance in the volume of e-waste is primarily due to three main reasons; increasing market penetration, replacement market and high obsolescence rate. Besides that, due to the increase in affordability of new products and technological advancements, it is easy to purchase rather than repair outdated equipment (Turaga et al., 2019). The increase in consumer demand, high rate of obsolescence, the short lifespan (replacement interval e.g. of mobile phones, personal computers), and the difference between production and recycling rates have also contributed to the increasing volume of e-waste over time (Ilankoon, 2018). Consequently, people end up with a pile up of DEEE. In addition, with high labor costs, and tough environmental regulations, developed countries ignore e-waste recycling and instead dump to developing countries where they may be recycled using primitive techniques with little regard for worker safety and environmental protection (Niinimäki and Karell, 2020). This has resulted in widespread environmental contamination. The disposed equipment and electronics, more so in an informal sector, are poorly handled through dumping in landfills, incineration and dismantling where e-waste is piled up with other domestic waste and soil, burnt in an uncontrolled environment and reused, respectively. High levels of environmental contamination can occur from e-waste recycling, putting residents in surrounding areas at risk of ecological exposure via inhalation or ingestion of contaminated water, air, and food supplies (Lundgren, 2012). Most e-waste is disposed of in landfills, while recycling efforts occur to recover valuable materials (Robinson, 2009). Thus, e-waste contains both valuable, as well as hazardous materials that require special handling and recycling methods. The different exposure sources to e-waste are commonly characterized as formal and informal recycling.

Global and country context of E-waste and problem statement

Heacock et al. (2016) and Baldé et al. (2015) assert that colossal quantities with tons of e-waste are produced globally with an estimate of between 20 million and 50 million metric tons annually. The global volume of e-waste has doubled in the last five years from approximately 20 million to 40 million tons annually (Islam et al., 2020). Forti et al. (2020) report an undocumented annual total of 50 tonnes (t) of mercury and 71 kilo tonnes (kt) of BFR plastics released into the environment globally, and consequently negatively impacting the health of workers. Western European countries, China, United States of America, Japan, and Australia are the major countries generating the most e-waste worldwide (Deathe et al., 2008). Scholars and practitioners claimed that 50 to 80 percent of e-waste produced in developed and industrialized countries are undoubtedly exported to developing nations (Heacock et al., 2016). The value of materials generated in e-waste in Africa is $3.2 (Forti et al., 2020).

The European Union (EU) is estimated to discard 0.6 Mt of e-waste into waste bins annually (Ravindra and Mor, 2019). Forti et al. (2020) report that the global amount of e-waste quantified in 2019 comprised mainly of small equipment constituting 17.4 Mt, large equipment constituting 13.1 Mt, as well as temperature exchange equipment comprising 10.8 Mt. They also show screens and monitors constituting 6.7 Mt, small IT and telecommunication equipment (4.7 Mt), and lamps representing a smaller share (0.9 Mt). An improper e-waste management contributes to global warming. Forti et al. (2020) reported a total of 98 Mt of carbon dioxide (CO_2) equivalent or approximately 0.3 percent of global energy related emission that were discarded from air conditioners and fridges. These are released into the atmosphere where they are managed in a non-environmentally sound manner.Meanwhile, in Uganda, there has been an increase in the number of discarded electronic and electrical equipment (DEEE) in government, the private sector and at the individual level (Gillwald et al., 2019; UNDP, 2016). Consequently, the import volumes of EEE have been growing at an annual average of 22 percent (UCC, 2018). Currently, 23 million people have telephones, 2.5 million have television sets while 90 percent of the people in Uganda have access to radios (Baluku and Kasujja, 2020). In Uganda, the e-waste generated in 2019 was 32 kilo tonnes (kt) whereas the e-waste that was documented and destined for collection and recycling in 2018 was at 0.18 kt (Forti et al., 2020).

The concerns about the effects on health due to chemical exposure and environmental degradation are increasing and yet the Government of Uganda is slow in addressing them despite available laws, legislations and guidelines on e-waste management. Moreover, disposal of plastic waste has attracted much more attention compared to e-waste by both government and civil society organizations.

This study provides environmental and human health impact of e-waste, its implications and some practical recommendations to address the challenges posed by e-waste generation.

Consequences of E-waste on human health and the environment

Health impact of E-waste

Numerous studies regarding the exposure to heavy metals and chemicals from e-waste have been conducted globally. It has been found that the impact of e-waste on both the environment and human health is overwhelming. Particularly, communities living near the e-waste recycling sites are prone to health and safety concerns such as inhalation of toxic chemicals and exposure to radiation (Jibiri, 2015). In South America, a study analyzed manual metal gathering by low-income youngsters and its relationship with increased blood lead levels as a result of lead exposure (Heacock et al., 2016). It was found that children and adolescents have had higher blood lead levels (BLL) compared to the normal levels (Ravindra and Mor, 2019). Blood test, urine test and hair are the most shared bio-indicator used to observe human exposure to contaminants of e-waste. Zhang et al. (2020) examined the exposure to phthalic acid esters (PAEs) that is common in e-waste recycling and reprocessing areas. Urine samples of residents of e-waste sites were obtained; where results indicated that the concentration of PAEs in their urine was significantly higher than that of occupants in other areas. They found approximately 22 percent of the dwellers in e-waste sites had hazard index (HI) values greater than one, an indicator of tolerable exposure levels beyond the threshold that might cause possible adverse effects. Zhang et al. (2020) also found 68 percent of residents in e-waste sites were in the age bracket of 0 to 18 years old. PAH identification using urine and hair by way of bio-indicators was likewise done for residents and workers close to the e-waste recycling area. They found no significant difference with respect to exposure level between e-waste dismantling workers and the residents. In another study, carcinogenic metabolites were detected in the internal hair of the respondents (Lin et al., 2020).

Awasthi et al. (2019b) opined that heavy metals exposure is a cause of acute and chronic respiratory and reproductive problems, cardiovascular and urinary disease and also irritations. Additionally, in Delhi, e-waste is reported to have contributed to respiratory track irritations, kidney and blood infections, lung cancer, nervous breakdown and brain diseases (Kowsar et al., 2010). Machete (2017) confirmed exposure of humans to toxic and poisonous metals that include arsenic cadmium and mercury with devastating human health effects in a study conducted in South Africa. Maphosa and Maphosa (2020) emphasized that e-waste comprised an array of toxic elements or materials like mercury, beryllium, lead and barium. Lu et al. (2015) in China also reported a high-concentration level of metals (lead) in the blood samples of children. Similarly, Tue et al. (2013), conducted a study in two informal e-waste recycling sites in Vietnamese urban areas and found higher levels of BFR and PCB in indoor dust compared to those in non-e-waste houses.

A study in Ghana by Cudjoe and Acquah (2021), indicated that contaminants or pollutants emitted substances that triggered burning eye irritation, asthma and other respiratory infections among others. Similarly, Asampong et al. (2015) established that e-waste workers have suffered from chest pain and acute respiratory infection. Agyei-Mensah and Oteng-Ababio (2012) also determined that about 50 percent of e-waste workers reported respiratory infections and chest pain as well as contracting various cancers. Rautela et al. (2021) established that burning of e-waste in landfills and open dumpsites lead to release of carbon-based pollutants, which affect the health of humans. Tetteh and Lengel (2017) discovered that unregulated e-waste recycling leads to the emission of hazardous ingredients that contaminate the environment, resulting in increase in cancer amongst the dumpsite workforce and persons within the vicinity. In addition, the human exposure to e-waste contaminants and pollutants will possibly affect their DNA. Awasth et al. (2018) in their assessment of possible genomic damages in workers involved in recycling E-waste presented a relatively strong correlation between the duration of processing e-waste and DNA damage. This was supported by health review of residents in the informal e-waste recycling sites. Grant et al. (2013) stressed that exposure to e-waste by workers and residents near the processing sites points to spontaneous abortions, stillbirths, premature births, and also reduced birth weight and length. Yu et al. (2017) and Gangwar et al. (2019) showed evidence that e-waste employees reported hearing loss, body pain, coughs as well as cuts. According to Maphosa and Maphosa (2020), the health impact includes cancer, asthma, nerves breakdown, hearing and visual problems, infant-mortality and births of disabled babies while the environmental impacts are air, water, soil pollution and life threats to wildlife. Nwagwu and Okuneye (2016) revealed that e-waste exposure to hazardous metals damages the nervous system, increases drug resistance, decreases mental capacity, causes skin infections, infant mortality, congenital disabilities, blood disorders, respiratory problems and other vital organs failure. Adults including workers in informal e-waste recycling sites and children are normally exposed to inhaling particulate matter and toxic fumes, through skin contact with corrosive chemicals and by ingesting water and contaminated food (Forti et al., 2020). Mothers also pass dangerous chemicals to children during breastfeeding and at times pregnancy, whereas young children increase exposure by frequently eating soil (Landrigan et al., 2019; Forti et al., 2020). Other health concerns include adverse learning and birth outcomes, altered neurodevelopment, DNA damage, adverse cardiovascular effects, adverse respiratory effects, adverse effects on the immune system, skin diseases, and hearing loss (Xu et al., 2020; Soetrisno et al., 2020; Amoabeng et al., 2020). With all these effects, players in the informal e-waste recycling sector who extract valuable materials like gold, still haven't adopted standardised precautional measures and use improper and unauthorized methods (Awasthi et al., 2018). Those without industrial gloves or masks are exposed to injuries by metals, glasses and toxic chemicals (Kowsar et al., 2010). Without protective equipment, toxic chemicals can cause skin cancer, anemia, carcinogenic tumors and hormonal problems (Ganguly, 2016). Adanu et al. (2020) found that EEE workers use hammers, stones, and other rudimentary equipment to dismantle e-waste in order to detach the sought for components. This is corroborated by Acquah et al. (2019) who state that e-waste employees rely on rudimentary equipment such as chisels and hammers that result in musculoskeletal injuries. Davis et al. (2019) also observed that e-waste recyclers used rudimentary and crude ways, such as burning to recover useful parts without due care on the effect to their health. There are also cases of accidents and physical injuries like cuts and burns caused during the breaking/dismantling of e-waste EEE (Awasthi et al., 2019a). This is supported by a survey by Soetrisno et al. (2020), who revealed that E-waste workers were at risk of absorbing hazardous substances through their skin as well as smoke inhalation. Soetrisno et al. (2020) also documented that workers that dismantled e-waste complained of persistent cough, skin infections and eye irritation. Injuries are sustained due to the use of rudimentary technologies such as hand sorting of elements, dismantling using stones, hammers and hitting on the ground to crush e-waste EEE (Adanu et al., 2020). Burns et al. (2019) established that E-waste workforces experienced lacerations or cuts to their hands as a result of manual procedures during recycling. Rudimentary and uncontrolled technologies are associated with harmful chemical exposures among vulnerable populations, women and children not an exception (Heacock et al., 2016). The problem is exasperated when the workers who sustain injuries fail to get medical attention, thereby increasing exposure of their wounds to more toxic chemicals (Davis et al., 2019).

Environmental impact of E-waste

Soil, air and water contaminations are examples of e-waste environmental consequences. Indeed, Grant et al. (2013) classified environmental hazards of e-waste as land, water and air (aerial) dangers. Seven metals that include copper, lead, calcium, molybdenum, tin, nickel and zinc, were detected in high concentration in soil and sediment samples from open burning sites, sediment samples besides rivers close to residents and e-waste processing sites. Soil contamination is a major environmental effect of unsustainable e-waste management (Adanu et al., 2020).The toxins that leach into the soil affect tree and plant growth. This makes such areas not suitable for growing food (Li and Achal, 2020). The process of breaking to remove copper yoke and subsequent dumping of cathode ray tubes, allow heavy metals including barium and lead to leach into the ground water and fresh waterways and also release contaminated phosphor (Gupta, 2014). When these toxins enter the human food supply, they can cause a number of health complications. The leakage of hazardous liquid chemicals such as acid contained in batteries of cars stain the soil giving it a dark colour (Adanu et al., 2020). Improper recycling activities such as manual dismantling and open burning pollute the soil and water bodies, as exhibited by the occurrence of fire retardants, river sediments and in soils (Uchida et al., 2018). Gupta (2014) states the process of de-soldering and removal of chips from printed circuit boards lead to the emission of brominated beryllium, cadmium, dioxins and mercury and other metals to the atmosphere. Dioxin compounds pollution on the soil have been confirmed in the e-waste recycling and processing sites where the concentration detected has been found to be higher than the maximum acceptable absorption based on the World Health Organization (WHO) regulation; mostly due to open storage practice and open burning (Suzuki et al., 2016). Uchida et al. (2018) in their multivariate analysis results, showed that high concentration of the metallic elements is strongly associated with E-waste processing. Additionally, soil analysis revealed copper accumulation from open-burning activity sites. Air contamination is another e-waste environmental consequences. E-waste affects the air when landfills are burned in incinerators, thereby polluting the air consumed by animals and humans. The heavy metals in landfills severely impact the atmosphere (Jayaraman et al., 2019). The toxic emissions mixed with virgin soil and air are harmful to the entire biota either directly (release of acids, toxic compounds including heavy metals, carcinogenic chemicals) or indirectly (via biomagnification) (Jayaraman et al., 2019). E-waste burning also increases the air pollutants concentration, particularly the particulate matter. Heavy metal concentration and also particulate matter level (PM10) was observed in air samples in e-waste site and surrounding areas due to open burning (Gangwar et al., 2019). Based on the blood analyses, the residents of e-waste burning sites were found to have the highest level of exposure in India (Gangwar et al., 2019).

On the other hand, the existence of contaminated surface water has adverse effects on the living water organisms as well as leading to biomagnification. Idrees et al. (2018) found illegal dismantling of e-waste as well as open-air burning of e-waste the main reason for high contamination or pollution by cadmium in groundwater in some Indian districts. The cadmium contamination level was found higher than the recommended regulatory threshold, showing grave groundwater system ~~e~~ toxicity. E-waste if not properly disposed negatively affects underground water which is not only used by humans but also other animals and birds.

The water ends up being unsafe for consumption (Li and Achal, 2020). The toxin from e-waste makes humans and animals sick and causes imbalances in the plant ecosystem. Liu et al. (2019) examined plasticizers flame retardants (PFRs), and also the PFR metabolites of water or aquatic snake samples in a contaminated pond. Results showed that biomagnification did not occur, bio-magnification factors (BMFs) less than 1, signify a bio-dilution determined by metabolism.Open burning, when recovering gold, copper, etc., from wires, discharges hydrocarbons into the air; thus causing air pollution. Open burning of wires and other e-waste to recover copper results in an environmental hazard because it releases hydrocarbons and ashes that include PAHs discharged into the soil, air and water. Besides, open burning of dismantled printed-circuit and boards leads to environmental hazards through the release of tin and lead to the environment (Gupta, 2014). Adediran and Abdulkarim (2012) uphold that soil pollution arising out of aerial deposition as well as irrigation is most likely to contaminate crops.

Indeed, in China, Fu et al. (2008) discovered soil contamination due to aerial deposition as the main source of contamination in rice, from toxic metals such as mercury, cadmium and lead. Crops close to or in locations contaminated with e-waste absorb and accumulate toxic heavy metals, thus posing a possible health risk to animals and humans that feed on those crops (Gupta and Gupta, 2007; Luo et al., 2009). Table 1 summarizes the existing toxic metals in identified types of E-waste and their impact on the environment and human.

Mechanisms/Techniques to alleviate E-waste damage

Electrical and electronic equipment contain some hazardous components that require appropriate handling and treatment to alleviate the adverse effects on the environment and human health as a result of improper disposal and recycling procedures. Chen et al. (2011) and Sheng and Etsell (2007) in general terms classified white goods as related to household appliance, grey goods (highly toxic) likened typically for computer, scanners, printers, and fax machines and lastly brown goods associated with televisions, camcorders and cameras. Personal computers comprise extremely lethal and toxic chemicals such as cadmium, lead and mercury among others (Chen et al., 2011; Sheng and Etsell, 2007). Some of the mechanisms and techniques to alleviate e-waste damage are reviewed below;

Chemical leaching techniques of metals from E-waste

Li and Xu (2019) considered the chemical leaching of copper (Cu) existing in waste PCBs in regard to its particle or element size, and by applying treated shredded or stripped copper particles of unwanted PCB with hydrogen-peroxide and sulfuric acid. Chemical leaching encompasses leaching either by acid use or usage of ligand supported complexion (Li and Xu, 2019). It may also be executed by involving complexometry, especially wherever ligands become complexed with metals. Similarly, chemical metal leaching from the e-waste can also be done through the use of various inorganic-acids such as hydrochloric acid, sulphuric acid and solution of nitric acid and sulphuric acid. Sodium hypochlorite (together with acid or alkali) can be utilized for the recovery of precious metals such as gold. Rautela (2021) utilized the organic solvents for heavy metal extractions such as aluminum (Al), iron (Fe), copper (Cu), silver (Ag), nickel (Ni), and gold (Au). Chemical leaching is known to be costlier to utilize compared to bioleaching.

Bioleaching of E-waste

Bio-leaching is a key technology and technique among main waste for already spent batteries and other electronic scraps. Bioleaching is an economical method of metal extraction through the use of living microorganisms in a process termed bio-hydrometallurgy or microbial mining. Bioleaching is commonly applied in commercial processes that involve processing of nickel, uranium, copper, zinc and cobalt. On the other hand, bio-oxidation is applicable in the processes involving gold. Largely it is the acidophilic bacteria group that plays a role in the bioleaching of heavy metals (recovery of metals from e-waste) arising from the wastes (Mishra and Rhee, 2010). The acidophilic groups succeed in acidic pH range from pH 2.0 to 4.0 and aid in the dissolving of the metals from the solid wastes phase into the aqueous phase. Microorganisms have the tendency of extracting metals from iron-containing ores or its sulfide and mineral concentrates. Sulphide and iron can be microbially oxidized so that it produces ferric ion with sulphuric acid that will eventually make possible the conversion of insoluble sulfides of metals (zinc, copper and nickel) into soluble metal sulfates readily recoverable from the solution.

Hybrid technique for metal extraction

As much as the bioleaching technique is cost effective, it is rather time consuming and unreliable in recovery of

Table 1. Existing toxic metals in identified types of E-waste and their impact on the environment and human health.

Toxic material	Weight (%)	Recycling (%)	Location	Environmental impact	Health impact
Lead	6.2988	5	CRT, Acid battery	Hazardous constituents' leaches out or leaks into groundwater and streams from landfills.	Central and peripheral nervous systems, Kidney failure, reproductive systems damage
Plastic	22.99	20	Cablings, computer mouldings	Dioxins are emitted or released into the air when the plastic elements are burned.	Produces dioxins and furans
Mercury	0.0022	0	Switches, batteries, housing	Mercury in water & deposits is the main concern, since in its highly toxic form can be consumed by animals, hence finding way to the human food chain.	Liver and chronic brain damage, causes damage to fetus as well as central and peripheral nervous systems.
Chromium VI	0.0063	0	corrosion protection, decorative hardener,	Chromium VI is primarily poisonous or toxic to organisms.	Lung cancer and DNA damage
Cadmium	0.0094	0	Battery, housing, CRT	Cadmium is toxic to plants, animals and micro-organisms.	Bone disease, long-term cumulative poison

Source: Bosshard et al. (1996), Pant et al. (2012), Kishore (2010), Chen et al., (2011), and Bala and Goel (2012).

metals in several cases (Ren et al., 2009). On the other hand, although chemical leaching is comparatively rapid and efficient, it poses its own environmental issues. Consequently, the proposed use of the hybrid technique which involves the combination of biological leaching and chemical leaching (through harmless chemicals), is anticipated to complement each other more effectively for metal extraction (Awasthi and Li, 2017). Frioui et al. (2017) investigated the feasibility and practicability of coupling electrodialysis (ED) to complexation reaction (CR) process, that is, an *in-situ* CR step to selectively recover and also concentrate several metallic cations with similar or different valences that is barely separable by means of conventional ED. Their results demonstrated high electro-separation performances for Cu/Cd and the Ag/Zn systems. It was recommended that the hybrid technology can extend the coupling electrodialysis potential for treatment of added-value metallic ion comprising wastewaters.

Pyrometallurgical process

Pyro-metallurgical process has been applied successfully in extracting lead from waste cathode-ray tube (CRT) (Mingfei et al., 2016). The process is utilized to remove or eradicate lead and some other nonferrous metals through addition of sodium carbonate powder (as a fusion agent), sodium sulfide (as a catalytic agent), as well as carbon powder used as a reducing agent coupled with the 94 percent lead removal efficiency rate (Li and Xu, 2019). Also, Zhang et al. (2020) utilized the metallic-iron for thermal reduction for extraction of lead with 99 percent guaranteed efficiency from CRT funnel glass. Furthermore, Thakur and Kumar (2020) applied the pyrometallurgical process for the extraction of lead nanoparticles through a carbon reducing agent, in 500 to 2000 Pa vacuum and 1000^{o}C temperature for 2 h.

Hydrometallurgical process

This technique is used through the application of acidic solutions on cathode-ray tube chimney glass, followed by the separation and cleansing processes directed to concentrate the metals. However, Ling and Poon (2011) state that some pretreatments like rinsing or cleaning with tap water on the CRT funnel glass as well as acid washing in 5 percent nitric acid for 3 h are carried out to overcome the metals strong bonding from glass thus increasing the lead solubility. Zhang et al. (2020) applied a strong alkaline solution that was combined with mechanical activation and chemical leaching as an innovative hydrometallurgical process with the lead elimination efficiency of 97percent. Yuan et al. (2015) was able to separate lead from the CRT pipe glass by pretreating it using hydroxyl ions produced throughout an

Table 2. Inclusion and exclusion criterion.

Inclusion criteria	Exclusion criteria
Human danger, environmental danger, E-waste, E-waste management.	Not detailed description
National documents or journals or conferences or technical reports	New and comparable study exists.
Abstracts in English.	Evaluation of existing studies in E-waste management.
Available SLR in E-waste management	Non availability.

Source: Primary data

Table 3. Primary electronic database used in the SLR.

Electronic Databases	Number of papers
Science Direct	15
Google Scholar	20
IEEE Xplore	04
Emerald	05

Source: Primary data

ion exchange reaction. However, hydrometallurgy process is not profitable whenever there is a significant rise in transportation distance.

Mechanochemical activation process

This process or technique is activated by physicochemical variations with wide applications. Yuan et al. (2013) pointed out that without the high temperature requirement, CRT funnel or chimney glass can be eliminated by applying the mechanochemical sulfidization reaction. This mechano-chemical sulfidization reaction or changes is started by co-grinding the cathode-ray-tube glass with the elementary sulfur in the atmospheric nitrogen (Yuan et al., 2012). Lead extraction from CRT tube glass is a cost-effective and with a quick lead recovery rate activated at 92.5 percent (Yuan et al., 2012), likened with 1.2 percent arising from an inactivation sample (Yuan et al., 2013). Yuan et al. (2012) stated that it can also lead to the detoxification of other lead related glass.

METHODOLOGY

The research evidence that analyzed the global state of human life and environmental consequences that are associated with e-waste management was summarized and narratively assessed the techniques related to alleviating the damage caused by the management of e-waste. Systematic Literature Review (SLR) was conducted following Kitchenham (2004) guidelines. SLR involves the evaluation and interpretation of all existing research appropriate to a specific research question or phenomenon of interest (Kitchenham, 2004). The SLR method involves the analysis of relevant primary researches and publications by identification of gaps, mapping, evaluation, aggregation and interpretation dependent on a precise research question or topic area. Klassen et al. (1998) describe a systematic review as a review where there is a comprehensive or all-inclusive search for relevant studies (researches) on a specific topic, the studies identified are thereafter, appraised and synthesized depending on predetermined and explicit methods. A systematic review collates all relevant empirical evidence appropriate to the pre-stated eligibility criteria to answer or address specific research questions. SLR uses clear and systematic methods selected with a view to minimize the impact of errors or bias, mitigating further trials, and thus provides more reliable findings where conclusions are drawn and appropriate decisions made (Brereton et al., 2007). SLR for long has been viewed as the leading technique in the collection and analysis of extant research work, where according to Brereton et al. (2007) focuses on phases that are: planning of the review, conducting the review and reporting the review. For this study, literature was searched to attempt to answer the following research questions: What are the human life and environmental consequences that are associated with e-waste management in Uganda? What technological techniques can be used to reduce the damage caused in the management of e-waste?

PLANNING THE REVIEW

A protocol is important to any SLR. The protocol, which is driven by research questions, defines the exclusion or inclusion criteria in choosing the primary studies as indicated in Table 2. SLR protocol is designed to guide the search procedure and process (Kitchenham, 2004), especially where relevant research papers are identified and automatically retrieved from electronic databases as well as manually from some target journals, government websites, and documents. Literature search process and procedure of the SRL involved querying of four (4) highly ranked sources of scholarly electronic databases that comprised Emerald, Science Direct, Google Scholar and IEEE Explore, shown in Table 3. However, we zeroed mostly on only Science Direct and Google Scholar since

Table 4. A four stage strategy Search.

Electronic Database (s)	First Search	Second Search	Third Search	Fourth
Emerald	1,059	109	074	00
IEEE Explorer	1,830	128	093	00
Science Direct	2,307	172	161	14
Google Scholar	3,123	208	083	21
Total	8,319	617	411	35

Source: Primary data.

they overwhelmingly had recent papers in our area of study as indicated in Table 3. Besides, it also avoided duplication of papers. Levy and Ellis (2006) affirm that selected electronic databases provide access to high impact information systems (IS) journals and top-quality peer reviewed conference proceedings in information systems. The key data sources accessed through the various electronic libraries provide a reasonable assurance that most relevant publications have been covered. Other secondary searches grounded on references originating from our principal sources were also performed. The study avoided questions that were not clear during the planning phase when planning the review.

CONDUCTING THE REVIEW

A thorough three-stage search strategy, as indicated in Table 4 was adopted. The search string used provided an exhaustive, comprehensive and thorough picture of E-waste consequences and management. Consistent and logical operators "OR" and "AND" was used to join the keywords of interest and consequently combined the keywords in the phrases. Kitchenham and Charters (2007) suggested the use of Boolean operators ("OR" and "AND") as well as application of their different but suitable combinations to support the refining of the search string. To guarantee avoidance of important materials, we performed additional explorations and searches on key authors of E-waste management, conference proceedings (Table 3). Consequently, studies that passed the screening procedure were finally designated for further analysis in this SLR. In order to find appropriate research articles, the keywords were applied in most E-waste literature originating from both developing and developed countries, including their synonyms or probable replacements. During the review, the literature from numerous or multiple sources was searched to avoid publication biasedness. Besides, the quality of the selected articles was assessed through a checklist.

Based on our research questions, the definition of the keywords were derived following a thorough database search. A search string was constructed using appropriate terms founded on the first research question where we ensured the first iteration involving both a manual and automatic searches dependent on a list of keywords arising from the electronic databases.

The search considered the title, keywords and abstracts of the articles that were used. In the first stage, search string comprised keywords like "E-waste management" OR "E-waste." The Boolean operators improved the searches by retrieval of top publications based on the indicated search string. To broaden the present study base and in order to produce a comprehensive search, we used top electronic databases for performing the search procedure and process. Based on the accessibility of articles, scientific databases that included Google Scholar, Science Direct, IEEE Xplore and Emerald were chosen.

(a) First, a refined search string that yielded 8,319 research articles was applied as presented in Table 3. The search had a variety of publications and articles from refereed journals, and government documentations to newspaper articles. We overlooked student articles altogether and excluded numerous retrieved researches that ignored aspects related to E-waste and those that included municipal and solid waste articles.

(b) In the second stage, we utilized the Boolean search string "consequences of E-waste" OR "consequences of E-waste management" in order to improve the search string further and produce better search results. This yielded 617 results.

(c) In a more refined manner, in the third stage, we used the Boolean search string "impact of E-waste on human health" OR "consequences of E-waste on the environment", in order to improve the search string further and produce better search results from peer reviewed publications. We also properly scrutinized every referred journal related to the health and environmental impact of E-waste. This yielded 411 results.

(d) The fourth and final stage involved the screening of candidate articles. We cautiously read all the article abstracts and conclusions with view of the individual full paper. Consequently, similar papers with matching titles were furthermore excluded retaining 35 papers for consideration in analysis and interpretations (as indicated in Table 5; only Science Direct and Google Scholar as justified earlier).

Table 5. Comprehensive impact of e-waste to the environment and human health

Authors	Electronic Database	Metal/Elements/Source	Consequences
Garlapati (2016)	Science Direct	Lead, Nickel & Zinc from CRTs, lead–acid batteries, cable sheathing, solder of printed circuit board and metal coatings.	Responsible for symptoms like vomiting, diarrhoea, convulsions, coma or even death and flora & fauna are adversely affected.
Chen et al. (2011)	Science Direct	Lead	Responsible for irreversible cognitive/ mental deficiency in children & behavioral and motor skill dysfunction across the lifespan.
Maphosa and Maphosa (2020)	Google Scholar	The toxic elements are emitted due to burning, dismantling, & acid leaching to recover precious metals from E-waste.	Contracting various respiratory & skin diseases and cancerous diseases.
Jaiswal et al. (2015)	Science Direct	Printed circuit boards, light bulbs, cathode ray tubes, televisions (1·5–2·0 kg per monitor), and batteries, Nickel and Lithium (Batteries), Barium - CRTs, & fluorescent lamps Beryllium - Power supply boxes, computers, x-ray machines, & ceramic electronics components.	Toxins from the metals that leach into the soil affects how trees & plants grow. Long exposures can cause cancer.
Park et al. (2017)	Google Scholar	The toxic elements	The chemical pollutants present in mixtures complicate the pollution situation and transferred to human either through direct or indirect exposure. The persons who are handling e-waste have chance of direct exposure to inhaling toxic chemicals, skin contact and ingestion.
Yu et al. (2017)	Google Scholar	Poor dismantling methods of E-waste	Exposure to a variety of injuries and illnesses. Results in cuts and body pain amongst informal workers. Scrap metal cutters reported coughs and rhinitis as the main health issues of the workers.
Meenambal (2011)	Google Scholar	Dumping of unusable parts into nearby water bodies.	That toxic mix of E-waste in landfills seeps or leaks into the soil & water, poisoning it, & thus endangering the life of the fauna and humans.
Leclerc and Badami (2020)	Science Direct	Mercury from LCD monitors, lamps & alkaline batteries, printed circuit boards relays & switches.	Occupational exposure leads to respiratory & skin disorders, including brain damage.
Balasubramanian and Karthikeyan (2017)	Google Scholar	Releases of deadly toxic airborne pollutants such as phthalates and dioxins into the environment.	Results into health issues such as anorexia, muscle pain, headache, weakness, brain damage, affects reproductive system, and causes death.
Asampong et al. (2015)	Google Scholar	Cadmium Sources include switches, springs, connectors, printed circuit boards, batteries, infrared detectors, semi-conductor chips, ink or toner photocopying machines, cathode ray tubes, and mobile phones.	Cancer-producing dioxins are released into the air whenever E-waste is burned. Burning e-waste creates very fine particles, which are then breathed in and can cause pulmonary & cardiovascular disease. E-waste workers reported acute respiratory infections and chest pains

Table 5. Contd.

Adanu et al. (2020)	Google Scholar	Poor dismantling methods	E-waste workers experienced lacerations & injuries to their hands due to manual processes during recycling. Lethal materials that shouldn't be consumed damage the soil where food is grown, damage the plants & grains that livestock eat, & the water needed to water crops, as well as drinking water for livestock & humans.
Burns et al. (2019)	Google Scholar	Poor dismantling methods	E-waste workers experienced lacerations to their hands due to manual processes during recycling.
Peluola (2016)	Google Scholar	Absorbing hazardous substances through their skin as well as smoke inhalation	Workers who dismantled EEE had skin and eye irritation while others complained of persistent coughing
Nwagwu and Okuneye (2016)	Google Scholar	Toxic metals, like lead. A single computer monitor has approximately 5 to 8 pounds of lead in it.	E-waste caused congenital disabilities & infant mortality, damage to the brain and other vital organs as well as respiratory, stomach, & skin infections. Toxic lead, can contaminate drinking water, which is already a precious commodity worldwide as multiple areas face record droughts and try to find ways to conserve water.
Machete (2017)	Science Direct	Confirmed human exposure to toxic metals such as arsenic, mercury, and cadmium catastrophic to human health.	The toxic components in e-waste have the ability to damage almost every system in the human body: the nervous system, reproductive system and skeletal system, as well as the brain, heart, liver and kidneys. They also cause birth defects. Communities in the neighborhood of recycling may be at risk of cancer, birth defects and mutagens associated with exposure to unregulated landfill hazards.
Laskar and Pal (2013)	Google Scholar	Nickel -Rechargeable NiCd-batteries or NiMHbatteries, electron gun in CRT	Nickel may cause allergic reactions.
Noel-Brune et al. (2013)	Google Scholar	Toxic chemical exposure to Cadmium.	Cadmium is found in cell phone batteries and can cause problems with learning, cognition, behavior and neuromotor skills in children. It can also cause kidney damage. Children & developing fetuses are particularly susceptible and evidence of adverse effects in early life via ecological exposure is increasing.
Grant et al. (2013)	Science Direct	Lead	Findings from most studies showed increases in spontaneous abortions, stillbirths, and premature births, and reduced birthweights and birth lengths associated with exposure to E-waste.

Table 5. Contd.

Jibiri et al. (2014)	Science Direct	Cadmium	Inhalation of toxic chemicals and exposure to radiation resulting in long-term health effects such as cancer. People living in e-waste recycling towns or working in e-waste recycling had evidence of greater DNA damage than those living in control towns.
Acquah et al. (2019)	Google Scholar	Inappropriate recycling method	Impacts on soil and health First, e-waste can have a damaging effect on the soil of a region. As e-waste breaks down, it releases toxic heavy metals. Such heavy metals include lead, arsenic, and cadmium. When these toxins leach into the soil, they influence the plants and trees that are crowing from this soil. Thus, these toxins can enter the human food supply, which can lead to birth defects as well as a number of other health complications. Adverse musculoskeletal health conditions among the workers
Amuzu (2018)	Google Scholar	Toxins like lead, barium, mercury, and lithium are also considered carcinogenic.	E-waste that is improperly disposed of, by residents or businesses also leads to toxins entering groundwater thus endangering the fauna including humans that survive on surface streams, ponds, and lakes. Many animals rely on these channels of water for nourishment. This exposure may lead to sickness in animals, damage the nervous system, decrease mental capacity, and caused blood disorders and imbalances in the planetary ecosystem.
Purchase et al. (2020)	Science Direct	Inappropriate recycling, recovery and dismantling methods	The process of burning (incineration) of disposed E-waste landfills on site or dumpsites can release hydrocarbons in the atmosphere, thus polluting the air that many animals and humans rely on. Hydrocarbons also contribute to the greenhouse gas effect that are considered to contribute to global warming.
Azodo et al. (2017)	Google Scholar	Inappropriate methods of E-waste	Disposal of these E-wastes without appropriate measures can cause health and environmental hazards to humans, livestock and the ecosystem.
Forti et al. (2020)	Google Scholar	Inhaling particulate matter and toxic fumes.	Health concerns include adverse learning outcome adverse birth outcomes, altered neurodevelopment, DNA damage, adverse cardiovascular effects, adverse respiratory effects, adverse effects on the immune system, skin diseases and hearing loss.
Alabi et al. (2014)	Science Direct	Toxic metals	Soils & plants were highly contaminated with toxic PAHs, PCBs, PBDEs, and heavy metals in both countries. These findings suggest that e-waste components/constituents can accumulate, in soil & surrounding vegetation, to toxic and genotoxic levels that could induce adverse health effects in exposed individuals. Also, damaging the DNA.

Table 5. Contd.

Decharat and Kiddee (2020)	Google Scholar	Toxic elements	Blurred vision prevalence, rash or itching, headaches and hand-and-feet numbness in recycling facility workers.
Amoabeng Nti (2020)	Google Scholar	Occupational exposure to particulate matter (PM)	Adverse respiratory effects e.g. reduced lung function.
Fischer et al. (2020)	Google Scholar	Burden of heavy metals, carbon-based or organic pollutants.	E-waste workers suffered significantly more from work-related injuries, back pain, and red itchy eyes in comparison to the (bystanders) control group.
Cong et al. (2018)	Science Direct	Air pollutants	Air pollution is a risk factor for cardiovascular disease, & cardiovascular regulatory changes in childhood contribute to the development & progression of cardiovascular events at older ages. Our results suggest that air pollution exposure in e-waste recycling areas could result in an increase in heart rate and plasma norepinephrine, implying e-waste air pollutant exposure impairs the sympatho-adrenomedullary (SAM) system in children.
Huo et al. (2019)	Science Direct	Lead (Pb) toxicity damages blood cells and disturbs the immune micro-environment.	Also, altered neurodevelopment & adverse effects on the immune system
Seith et al. (2019)	Google Scholar	lead, cadmium, copper, zinc, nickel	Skin diseases and adverse birth outcomes.
Soetrisno and Delgado-Saborit (2020)	Science Direct	Mn, Pb, Hg, As and Cd	Adverse learning outcomes
Dai et al. (2020)	Science Direct	Lead (Pb) and cadmium (Cd) levels.	Hearing loss
Zhang et al. (2020)	Science Direct	Exposure to cadmium (Cd) during pregnancy	Adverse birth outcomes. Significant decreases in birth weight, Low birth weight is an important determinant of mortality, morbidity and disability in infancy, and also has a long-term impact on health outcomes in adult life.
Davis et al. (2019).	Science Direct	Air pollutants through open burning of metals.	Elevated cancer incidence.

Source: Acquah et al. (2019), Adanu et al. (2020), Alabi et al. (2014), Amoabeng Nti (2020), Amuzu (2018), Asampong et al. (2015), Azodo et al. (2017), Balasubramanian and Karthikeyan (2017), Burns et al. (2019), Chen et al. (2011), Cong et al. (2018), Dai et al. (2020), Davis et al. (2019), Decharat and Kiddee (2020), Fischer et al. (2020), Forti et al. (2020), Garlapati (2016), Grant et al. (2013), Huo et al. (2019), Jaiswal et al. (2015), Jibiri et al. (2014), Laskar and Pal (2013), Leclerc and Badami (2020), Machete (2017), Maphosa and Maphosa (2020), Meenambal (2011), Nwagwu and Okuneye (2016), Noel-Brune et al. (2013), Park et al. (2017), Peluola (2016), Purchase et al. (2020), Seith et al., (2019), Soetrisno and Delgado-Sabori (2020), Yu et al. (2017), Zhang et al., (2020)

REPORTING THE REVIEW

Prior to paper and journal selection for SLR use, duplications were avoided by ensuring repetitions for the same studies in other journals, where the first authors appear in two or more journals of the same study were properly checked. However, choices for comprehensive papers were inevitable in some instances. Based on the research questions, a systematic literature search was performed covering the period of January 2010 to February 2021 on applicable scientific journals and document reviews.

We narrowed down our search from January 2015 to December 2020 in order to acquire relevant content. The mounting demand for digital technologies is growing human life quality at an unprecedented rate, as well as E-waste management emerging as one of the major threats to government and industrial bodies (Somayaji et al., 2019; Krishnan, 2011). E-waste collection causes numerous problems such as resource scarcity and environmental effluence, and also results in the development of various health hazards to the human population (Somayaji et al., 2019). The most outstanding, 35 papers from the electronic databases, constituting 100% of the publications emphasized the devastating consequences of E-waste on human health. The consequences of E-waste to the environment are overshadowed in the findings, calling for a deliberate effort by governments to sensitize their citizens about the dangers of E-waste to the environment.

CONCLUSION AND POLICY IMPLICATIONS

This study provides a comprehensive impact of E-waste to the environment and human health based on a SLR. Practical and technological solutions and recommendations were also provided to minimize future catastrophes from E-waste to policymakers and Theoretical contributions and prospects for future research. The environmental and health impact instigated through informal E-waste recycling is based on community exposure and environmental contamination. Community exposure is by food, air and water as well as home-based workshops and occupational exposure by inhaling smokes from burning wires and circuit boards, fetuses are exposed when expectant mothers engaged in E-waste disposal. Environmental contamination is caused by leaching of substances from stored electronics or landfills, contaminants entering the food system and water system through crops, livestock and fish. Others include contamination through dumping acid into water bodies and particulate matter, furans and dioxins from dismantling electronics. In children, contamination is caused by intake of contaminated dust on surfaces and playing or living with dismantled electronics. The most common discovered adverse effects include: fetal loss, premature birth, low birth weight, spontaneous abortions, and congenital malformations; abnormal thyroid function and thyroid development; neurobehavioural disturbances; and genotoxicity. Children and developing fetuses are particularly susceptible and evidence of adverse effects in early life via ecological exposure is increasing. In addition, lead and cadmium cause damage to the kidney, the nervous and blood systems. Mercury leads to skin and respiratory disorders and chronic brain damage. Meanwhile BFR disrupts the endocrine system functions whereas beryllium causes skin diseases like warts and carcinogenic or lung cancer. Besides, toxic elements from E-waste pollute water, air and the soil within the environment that in turn impacts on human health through either indirect or direct contact. In fact direct exposure to E-waste through inhaling lethal chemicals, ingestions and skin contacts by handlers of waste is very common together with vulnerability of expectant mothers and children.

Ultimately, applicable policy instruments and tools considered include taxes and product fees and taxes where manufacturers engage in collection of E-waste, including recovery to deter harmful components from incineration and landfills. Initiatives such as establishment of public-private recycling center managed by E-waste collectors with initial support from EEE importers or producers, can lead to sustainable management of E-waste in the long-run. Government could have this strengthened by recognizing or formalizing E-waste picking/collection and processing as a legitimate economic activity for job creation established for sustainable E-waste management. Besides, formalization of the informal sector in a bid to promote sustainable E-waste management can be supported through the establishment of a cooperative society with a full technical educational role for all E-waste actors. These include consumers, recyclers, refurbishers, authorized government agencies, manufacturers and civil society organizations among others.

The use of appropriate technologies (techniques) such as chemical leaching, and mostly bioleaching of E-waste for disposal, together with handling and treatment to reduce its harmful effect on the environment and humans were suggested. Also, the hybrid technique which involves the combination of biological leaching and chemical leaching is proposed for an effective metal extract in addition to the use of other eco-friendly technologies. Besides, both hydrometallurgical and pyrometallurgical recycling techniques and processes play a vital role in heavy metals recovery due to high gas flux temperature, energy density, and ionization process that increases reactivity.

Future research through systematic literature research will consider using the virtualization approach (Krishnan et al., 2013), which is an optimization technique used to find the solution for E-waste collection, server utilization, resource management, load balancing, and recycling, thus overall, E-waste reduction.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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