E-Waste Management and Practices at Zimbabwe's Higher Education Institutions

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Developing countries have embraced ICTs to participate in the knowledge economy, achieving double-digit annual growth in usage. Obsolete ICTs become e-waste, and developing countries do not have specific policies. Higher Education Institutions (HEIs) significantly contribute to the e-waste burden. E-waste contains hazardous substances which threaten the environment and human health while containing rare earth minerals worth billions. Seventeen HEIs participated in the study. Results show that all institutions kept obsolete ICTs for up-to 36-months, half disposed of as garbage, and a tenth took for recycling. The study recommends the adoption of sustainable practices such as, reduce, recycle and reuse.

Keywords: e-waste, e-waste management, policies, disposal, higher education institutions, environmental and health problems

INTRODUCTION

The past decades have seen a surge in the adoption of electrical and electronic equipment (EEE) such as televisions, radios, computers, and music gadgets. The last few years have witnessed rapid economic growth and the rise of the knowledge economy where information and communication technologies (ICT) are pivotal in driving the global economy. The developing world has not lagged in adopting ICTs to access information and services related to health, education, commerce, and participating in the global economy (Maphosa & Maphosa, 2020; Kumar & Dixit, 2018). The COVID-19 pandemic forced governments to adopt ICTs to drive almost every global economic sector, reducing face-to-face interaction and halting the pandemic's spread. This resulted in an increase in adoption and use of these technologies by developing countries. The 4th Industrial Revolution has witnessed over 25 billion Internet of Things (IoT) devices supporting industrial automation, smart cities, and smart campuses (Schumann, Baum, Forkel, Otto, & Reuther, 2017; Gartner, 2015). The developing world has witnessed tremendous demand for ICTs, resulting in double-digit growth (Heeks, Subramanian, & Jones, 2015).

Computers and mobile phones are now associated with our daily activities. This massive demand for EEE has not spared higher education institutions (HEI) to support learning and administrative functions. HEIs use high-end computing devices and fast-paced networks to harness data vital for the knowledge economy. HEIs embrace technologies that support twenty-first-century learning where learners create, share, and collaborate with their peers during the learning process (Makaramani, 2015). HEIs are adopting smart services by integrating the virtual world with physical infrastructure and applying big data, IoT and blockchain to manage resources (Maphosa, 2020). Chitotombe (2013) observed that many HEIs had resorted to acquiring used second-hand EEE from the West due to Zimbabwe's economic crisis.

When EEE or their component parts have reached their useful lifespan, or the user no longer finds the equipment usable, they are discarded and disposed of and referred to as e-waste. E-waste is increasing at an alarming rate as the EEE's product lifespan has drastically reduced, and high volumes become obsolete as it can no longer support new applications. New technologies such as the 4th Industrial Revolution, IoT, blockchain, artificial intelligence, big data and consumer demand for new products fuel e-waste. EEE use in higher education has been phenomenal, but improper disposal of obsolete EEE poses human health and environmental challenges. Improper handling of e-waste from HEIs is a significant and growing threat. Several universities have been replacing the Cathode Ray Tube monitors replacing them with environmentally friendly Liquid Crystal Displays, and this has seen the volume of e-waste increasing (Agamuthu, Kasapo, & Nordin, 2015). Ogbomo, Obuh and Ibolo (2012) report that several Nigerian institutions of higher learning have adopted twenty-first-century tools to support teaching and learning, yet the institutions have no strategies to manage the resultant e-waste.

Singh, Li and Zeng (2016) posit that the advent of new EEE designs and the rise in demand for devices that can process vast amounts of information contribute to the continuous growth of e-waste. Early obsolescence results from changes in consumers' lifestyles and consumption patterns and shortened product life spans (Hossain, Sulala, Al-Hamadani, & Rahman, 2015). The rapid economic growth is also fueling EEE demand, and improper disposal poses a significant threat to the environment and human health. E-waste is the fastest-growing stream of solid waste and has become a pressing global issue because of its detrimental effect on the environment and human health (Rochmana, Ashtona, & Wiharjoc, 2017). Agamuthu and Dennis (2013) noted that the production of cheap EEE and fast-evolving technologies would fuel e-waste. When a new product is released, thousands of earlier working ones are discarded, thus fuelling e-waste. The global e-waste would reach 53 million metric tons by 2021 (Baldé, Forti, Gray, Kuehr, & Stegmann, 2017). Mmereki, Li, Baldwin and Hong (2016) concurred that rapid technological advancements had fueled e-waste, with over a billion computers expected to be obsolete by the year 2020. Singh et al. (2016) report that e-waste is growing by about 5% per annum in the West, at a rate three times faster than municipal waste. Used EEE is exported to most developing countries to bridge the digital divide, allowing remote and marginalised communities to join the global village and participate in the global market (Junghoon, Dulal, Hyoung, & Shin, 2012). Unfortunately, the recipient countries lack financial and technological resources to manage the resultant e-waste. The developing world has become a digital dumping site for the West (Maphosa & Maphosa, 2020; Omobowale, 2012).

Improper handling and recycling of e-waste is an environmental risk and a health hazard as the burning and incineration results in the release of hazardous pollutants (Borthakur & Govind, 2018). E-waste is a global problem as over 80% of the global e-waste is processed informally with contaminants being released into the environment (Perkins, Drisse, Nxele, & Sly, 2014). The majority of the e-waste processed by illegal and informal recyclers is in developing countries, who use rudimentary and elementary tools to breakdown the components to extract precious materials (Kumar, Holuszko, & Espinosa, 2017; Arif & Afroz, 2014). Amankwah-Amoah (2016) reported that informal e-waste workers suffered from gastro-intestinal, skin cancers and other infectious diseases. Most e-waste is disposed of through burning and leaching in dumpsites and landfills in developing countries, causing environmental and human health hazards (Baldé, Kuehr, & Blumenthal, 2015). People living near dumpsites and landfills are at risk as toxic gases and chemicals are released into the environment through burning, acidification and incineration. Bakhiyia et al. (2018) concluded that vulnerable populations who live near dumpsites such as pregnant women, children and the elderly were the most affected.

Most countries in the developing world do not have specific laws targeted at managing e-waste but have to rely on legislation that deals with hazardous waste (Maphosa & Maphosa, 2020). Kumar and Dixit (2018) highlighted that lack an appropriate legal framework and inadequate socio-technical systems were significant obstacles to tackling e-waste challenges in most developing countries. Ravi (2015) also noted that the lack of policies and coordination among various stakeholders have resulted in ineffective e-waste management. Zimbabwe does not have specific legislation covering the management of e-waste and is relying on outdated policies meant to handle hazardous substances (EMA, 2018). Gweme, Maringe, Ngoyi and Stam (2016) concluded that Zimbabwe was failing to exploit the rare and precious minerals found in e-waste, which negatively affected its ability to manage and recycle e-waste. Lack of e-waste management policies has seen open dumping as the prevalent disposal method, which results in highly toxic chemicals being released into the environment and causing severe human health challenges (Chitotombe, 2013).

The study aimed to establish the level of e-waste awareness, and establish strategies used by HEIs in managing e-waste and establish some of the barriers to effective e-waste management. Reviewed literature suggests that there is scant research focusing on e-waste in Zimbabwe, at the same time, more than 50% of educational institutions were established in the past decade and have become significant contributors to the national e-waste output. To date, there has been limited action in integrating e-waste management into the university curricula to influence e-waste practices. The research also contributes to the body of knowledge on e-waste management at HEIs. The study plays a significant role in raising awareness and promoting environmental education to a relatively new yet growing problem. One challenge that the country faces is quantifying the amount of e-waste it generates (Chitotombe, 2013). The output of this research could be useful in lobbying the national government on establishing national policies and legislation for e-waste.

RELATED WORK

Developing countries have embraced ICTs to drive socio-economic development to achieve the Sustainable Development Goals, but lack of policies and infrastructure to manage the resultant e-waste poses severe threats to the environment and human health (Baldé, et al., 2017). Nnorom and Osibanjo (2011) note that the absence of basic infrastructure and policies to manage e-waste has seen e-waste being handled by informal backyard recyclers who resort to open burning and dumping, thereby contaminating water bodies and the environment. E-waste is the fastest-growing stream of solid waste, Forti (2020) revealed that e-waste had grown by 21% in the last five years, and only 17.4 % of the 53.6 million tons generated in 2019 was recycled through formal means.

Scholars estimate that developing countries will dispose of over 700 million computers, while developed countries will dispose of over 300 million computers in 2030 (Sthiannopkao & Wong, 2013). Yu, Williams, Ju and Yang (2017) predicted that developing countries would account for over 50% of global e-waste by 2018. These trends show that the developing world will experience more problems related to improper e-waste management. Most developing countries' challenges in managing e-waste emanate from illegal exports of e-waste disguised as commercial goods and cleared corruptly (Amankwah-Amoah, 2016; Hopson & Puckett, 2016). Over 80% of e-waste produced by developed countries is exported illegally into developing countries (Yu et al., 2017; de Oliveira, Bernardes, & Gerbase, 2012; Kumar & Dixit, 2018; Maphosa & Maphosa, 2020). Another study also revealed that 77% of e-waste in Nigeria was illegally exported and corruptly cleared (Baldé, et al. 2017).

Forti (2020) estimated that over 50 tons of mercury are released into the environment from illegal and informal recycling. Borthakur and Govind (2018) report that e-waste should be appropriately managed as it contains toxic elements including lead, chromium, cadmium and poly-brominated biphenyls. Luo et al. (2011) found out that soils and water points near informal treatment plants contained heavy metals which contaminated the food chain. Informal treatment of e-waste results in elements such as lead being released into the grazing lands and water bodies, affecting animals that graze on the land and the fish; and ultimately the human beings who consume the poisoned meat and the fish (Sing et al. (2016). The hazardous elements cause severe health conditions such as brain damage, various cancers, kidney failure, congenital disabilities, and fatalities (Babu, Parande, & Basha, 2007). Informal e-waste recovery methods result in the release of ozone-depleting elements and organic pollutants. These elements include polychlorinated and brominated flame retardants (Baldé, et al. 2017; Bakhiyia, Gravela, Ceballos, Flynnd, & Zayeda, 2018). Rochmana et al. (2017) noted that informal e-waste workers and those residing within the surrounding environment are exposed to toxic elements released through the use of inappropriate tools and lack of regulation.

Proper e-waste management is a contemporary issue and acceptable recycling results in the recovery and the extraction of precious and rare earth minerals such as copper, aluminium, gold, silver, barium, palladium and iridium and others (Borthakur and Govind (2018). To date over 500 million tons of e-waste have been recycled globally with an annual turnover of US$160 billion through the recovery of precious metals, offering lucrative business enterprise for developing countries (Diaz, Lister, Parkman, & Clark, 2016). The value of discarded e-waste stood at US$57 billion in 2019, higher than the GDPs of most African countries (Forti, 2020). Baldé et al. (2017) estimated that the value of precious minerals in e-waste stood at over 55 billion Euros in 2016. Ghana is one of the leading African countries on e-waste management, and studies reveal that the country generated US$268 million in 2016 from various recycling activities, and the sector employs about 200, 000 people (Daum, Stoler, & Grant, 2017). The total amount of gold used in the manufacture of EEE over the past 20 years exceeds 300 tons per annum and over 50% of the gold can be recovered through formal recycling processes from e-waste (Goleva, Schmeda-Lopez, Smart, Cordera, & McFarland, 2016). Over 24kgs of gold and 250kgs of silver and over 9 tons of copper can be recovered by recycling a million mobile phones, together with other precious minerals (Digital Journal, 2016).

Agamuthu et al. (2015) established that the average life span of a computer was 3-4 years, two years for a laptop, 3-5 years for a printer and five years for a monitor. Other scholars noted that the computer's life span was shortened from about five years in 1997 to about two years in 2005, while the mobile phone was reduced from 30 months in 1995 to less than 20 months in 2005 (Bakhiyia et al., 2018). Some of the used EEE exported to Africa is over 20 years (Maphosa & Maphosa, 2020). Developed countries export over 80% of e-waste to developing countries (Debnatha, Roychoudhuri, & Ghosh, 2016). Amankwah-Amoah (2016) revealed that about 40% of used EEE exported to Africa was non-functional and unrepairable e-waste. The Basel Action Network has noted with concern that some developed nations are dumping e-waste disguised as the provision of cheaper ICTs that can help developing countries bridge the digital divide (Baldé et al., 2015). Organisations such as Computer Aid International and Worldloop have been exporting refurbished computers to many HEIs in Africa (Reddy, 2016; Maphosa & Maphosa, 2020). Second-hand computers have a very short useful life span, which has fueled e-waste as they are quickly discarded, while some computers never work. There are tangible benefits associated with the use of second-hand EEE imported from developed countries (Amankwah-Amoah, 2016). However, developing nations face challenges related to the growing informal sector, lack of policies, and inadequate infrastructure, making it challenging to manage the resultant e-waste.

Developed countries have crafted specific policies and legislation that govern the management of e-waste and has seen manufacturers paying consumers for products that they return which have reached obsolescence (Khan, Lodhi, Akhtar, & Khokar, 2014; Islam et al., 2016). Tsan (2015) reported that Australia had recycled over 33% of obsolete computers by 2014, though this was about 10% of the set targets. Very few countries in Africa such as South Africa, Rwanda and Uganda have enacted specific e-waste policies and laws that enforce its management (Baldé et al., 2015). E-waste will flow unabated into poor developing countries due to the enormous appetite for second-hand equipment and lack of policies to enforce its management (Edumadze et al., 2013). Lack of specific e-waste policies has seen most of the e-waste being treated as general municipal waste and often disposed of in dumpsites and landfills through burning and leaching which cause severe environmental degradation and human health hazards (Baldé et al., 2017; Ikhlayel, 2018; Diaz et al., 2016). Solomon (2010) raised three issues that can help protect the environment from the effects of e-waste such as education and awareness, policies and legislation and instilling ethical behaviour.

Higher learning institutions are significant contributors to e-waste, yet a few studies have been conducted in developing countries such as Zimbabwe. Some of the institutions have grown to the size of small municipalities. As most industries in Zimbabwe closed due to the country's economic challenges, educational institutions have become some of the largest contributors of e-waste. One serious challenge in managing e-waste in Zimbabwe is that the economy has become highly informal and therefore, e-waste tracking and management is a challenge. Over 50% of HEIs in Zimbabwe were established in the past decade. Similary Edumadze et al. (2013) found out that there was a proliferation of university campuses in Ghana. Agamuthu et al. (2015) conducted a study across Malaysian universities and found out that the institutions were at different e-waste management stages. Another study in Nigeria revealed that e-waste output from obsolete computing devices was high, yet the institutions did not have proper disposal methods (Ogbmo et al., 2012). However, there were very few studies conducted to investigate e-waste management in universities.

Worldloop has established recycling plants in Kenya, Tanzania and Rwanda, highlighting successful partnerships between institutions in the Global North and those in the Global South (Reddy, 2016). The Kwame Nkrumah University of Science and Technology (KNUST) and Technical University of Munich (TUM) from Germany partnered to form a consortium to recycle e-waste generated by KNUST (TUM, 2020). HEIs in developed countries adhere to high environmental protection standards and promote green computing initiatives (Agamuthu et al., 2015). The University of Sydney in Australia collected and recycled 120 metric tons of e-waste, and some of the EEE was reusable (Agamuthu et al., 2015). In their study at an Iraqan University, Arif and Afroz (2014) proposed integrating e-waste management in the university curricula to increase awareness and cultivate a culture of responsible and environmentally sustainable management of e-waste. The establishment of proper e-waste management and recycling will improve environmental management and contribute to revenue generation (Agamuthu et al., 2015). E-waste is accumulating at an alarming rate in Africa as the continent is the largest generation second-hand EEE recipient. However, very few studies have been conducted on e-waste management practices at HEIs in developing countries such as Zimbabwe.

METHODOLOGY

A quantitative study was used to gather the views of ICT directors from the country's public and private universities. A total of 17 universities, of which 11 are public, and six are private, were targeted for the study. Universities were chosen in the survey as their enrolment numbers have been ballooning, signifying growth in a country where industries have shut down due to a prolonged economic crisis. Universities have therefore become top producers of e-waste in the country. The research was conducted during the COVID-19 lockdown through an online questionnaire survey targeting ICT directors or their deputies. The participant's rights, such as their anonymity, and that of their institutions and their voluntary participation, were outlined. The first part of the questionnaire collected data on the type of EEE that the institution possessed, frequency of replacement, and determining if the institution had acquired second-hand EEE. The remaining part sought to gather information on awareness of e-waste, knowledge of the precious and toxic elements therein, disposal methods, environmental effects of improper disposal, availability of institutional e-waste policies, and barriers related to e-waste management. A five-point Likert scale was to measure the levels of agreement and disagreement on some of the questions.

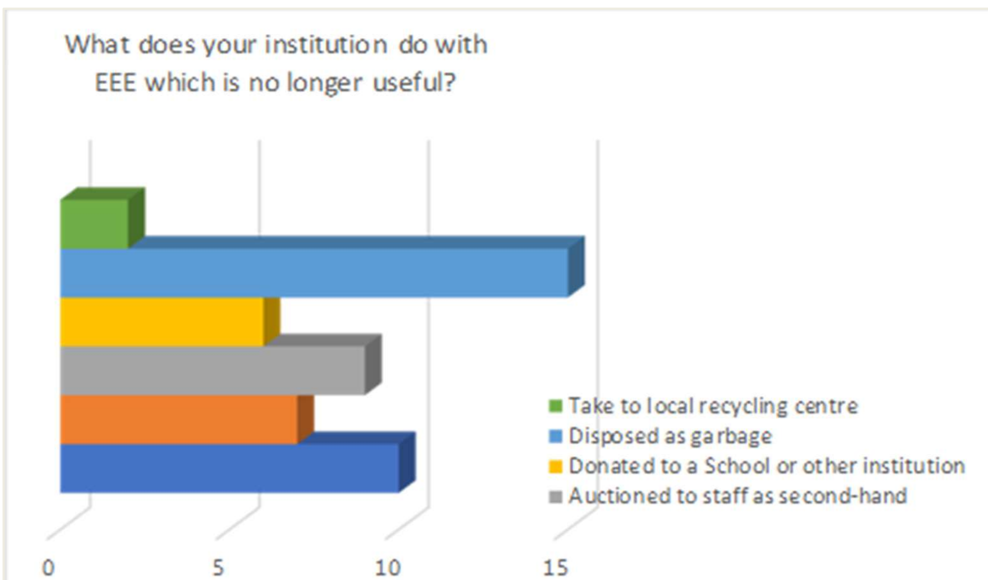
RESULTS AND DISCUSSION

A total of 16 institutions completed the questionnaire giving a response rate of 94.12%. All the universities had computers ranging from over 500 to over 5000. Over half of the institutions (56.25%) had 1000-5000 computers, 18.75% had less than 1000 computers, and 25% had over 5000 computers. Both public and private universities recorded between 100 to over 2000 obsolete computers. All the institutions had received donated second-hand computers or imported refurbished computers from developed countries. The participants agreed that the lifespan of new computers was about five years while that of imported refurbished computers was about one year. Based on these results, all institutions replaced their computer equipment and related peripheral devices after five years and continuously replaced consumables such as toners and ink cartridges. Over 43.75.5% of the institutions had 100-1000 obsolete computers, 37.5% had between 1000-2000 obsolete computers while 18.75% had over 2000 obsolete computers. The results are consistent with Agamuthu et al. (2015) who established that the universities under study replaced their computers after 3-5 years. Three-quarters of the participants were aware of the effects of e-waste on the environment.

Disposal Methods

The study sought to establish how institutions handled obsolete computers and consumables. About 75% of the institutions' stored obsolete equipment in storerooms for 12 months to 30 months, as shown in figure 1. All the participants disposed of their e-waste with general solid waste whose destination is landfills and dumpsites, which has adverse effects on the environment and human health. The finding is also similar to that of Agamuthu et al. (2015) who found out that three-quarters of the institutions surveyed in Malaysia disposed of e-waste together with municipal waste. The finding is in line with observations by Baldé et al. (2017) and Ikhlayel (2018). They noted that many developing countries lacked recycling infrastructure, resulting in the burning of e-waste in dumpsites and landfills. Ogbomo et al. (2012) and Wang et al. (2017) also concluded that the lack of appropriate e-waste collection systems impeded e-waste management efforts. Although three-quarters of the participants were aware of the environmental and human effects of improper disposal of e-waste, the majority still disposed of e-waste with municipal waste. The findings are similar to those of Borthakur and Govind (2018), who observed that high levels of awareness did not translate to responsible e-waste disposal. The results are different from those of Azodo, Ogban and Okpor (2017), who found out that only 18.5% of the Nigerian university participants placed their e-waste with ordinary trash. Although about 25% of the institutions are technology-based, no institutions had a recycling facility. Over half of the institutions (56.25%) auctioned used, and obsolete computers and 43.75% of HEIs stripped some of the functional components for spare parts.

FIGURE 1
E-WASTE DISPOSAL METHOD

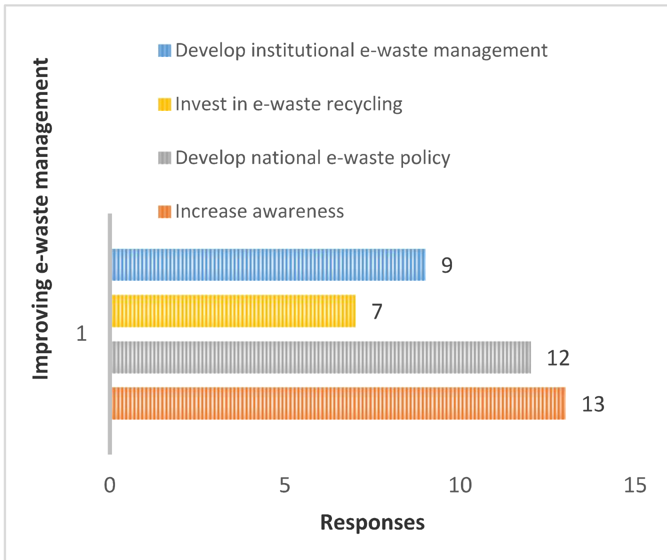


Handling of E-Waste

Perkins et al. (2014) contended that the most effective way of managing e-waste was to recycle, reuse and reduce. The results of the study show that 81.3% of the institutions preferred to replace obsolete EEE. The results show that institutions did not have a positive attitude with regards to proper e-waste disposal. In their study, Agamuthu et al. (2015) established that most participants preferred to replace the obsolete EEE or the faulty components instead of repairing. In a similar study, Bakhiyia et al. (2018) also noted that respondents preferred to replace obsolete or damaged EEE thereby weakening recovery and repair prospects. The findings are contrary to a study by Borthakur and Govind (2018), who established that 85.3% of the participants were willing to repair and recycle e-waste. A study done at a university in Nigeria revealed that 41.6% of the participants preferred to fix and reuse obsolete EEE with only 19.9% choosing to replace the EEE (Azodo et al., 2017). HEIs in Zimbabwe are fueling e-waste generation as they did not prioritise recycling and reuse, which are sustainable ways for managing e-waste.

About 37.5% of the institutions donated used EEE to schools, and surprisingly no institution made a follow-up on how the schools handled the e-waste. It appears that the institutions were shifting the burden of managing e-waste to even more vulnerable institutions. Two institutions (12.5%) sent their e-waste for recycling. A similar study by Arif and Afroz (2014), established that only 13% of universities in Iraq sent their e-waste to a recycling centre. In their research, Agamuthu et al. (2015) found out that there was little flow of e-waste to recyclers from Malaysian universities. Over two thirds (68.75%) of HEIs kept their e-waste in storerooms. The findings are comparable to those by Agamuthu et al. (2015) who established that universities in Malaysia stored up to 60% of their e-waste in storerooms. The findings are contrary to those of Azodo et al. (2017), who established that only 13% of the respondents preferred to store obsolete EEE.

FIGURE 2
HOW E-WASTE MANAGEMENT CAN BE IMPROVED



How to Improve E-Waste Management

Participating institutions acknowledged that e-waste was a significant threat to the environment and human health. Institutions proposed several ways to improve e-waste management as shown in figure 2. One of the major impediment to e-waste management relate to lack of awareness. Therefore, 80% of the participants recommended the deployment of e-waste awareness and campaign programmes across institutions. Three-quarters of the participants noted that the government should establish national policies and legislation specific to e-waste management. Over half of the participants (56.25%) suggested that institutions should develop their policies to manage the e-waste they generate. The suggestions are similar to those of Edumadze et al. (2013), and Solomon (2010) who established that e-waste awareness, establishing a national framework and local level policies were crucial for successful management of e-waste. However, Borthakur and Govind (2018) observed that high levels of awareness did not translate into responsible e-waste management.

Existence of Local and National Policies

Almost all the participants (93.75%) were not aware of a national e-waste policy or related legislation; only one participant (6.25%) thought such a policy existed. This confirms Chitotombe (2013)'s findings, who established that Zimbabwe did not have a national e-waste policy, which resulted in e-waste being treated as general solid waste. The current e-waste disposal methods suggest that most institutions did not have local-level policies to manage the e-waste they generated. Only 31.25% of the HEIs had established e-waste management policies, while 68.75% indicated that they did not have such policies. About 56.25% of the participants were knowledgeable of the precious minerals found in e-waste. The majority of the participants (93.75%) had good knowledge of toxic chemicals found in e-waste. This high percentage did not translate into effective disposal of e-waste. The findings are similar to those of Borthakur and Govind (2018). The scholars observed that 81.6% of the participants in a study in India considered e-waste to be harmful to human health and the environment but this did not translate to proper e-waste handling.

CONCLUSION AND RECOMMENDATIONS

The study revealed that most universities had large stockpiles of e-waste due to the unavailability of recycling infrastructure, national and institutional policies. All the universities had procured second-hand computers or received a donation of used computers, yet over two-thirds of the institutions did not have e-waste management policies. The results showed that most institutions stored e-waste for up to 36 months, thereby compounding e-waste accumulation challenges. The extended period for e-waste storage was due to a lack of policy, precise disposal methods, and recycling infrastructure. Most institutions preferred to replace old and obsolete EEE, and very few institutions considered options to reuse, reduce and recycle. All the institutions discarded e-waste and municipal waste which naturally finds its way into dumpsites and landfills where it is informally recycled. Informal recycling disregards environmental protection and results in releasing ozone-depleting gases and toxic chemicals into the environment. As institutions embrace industry 4.0, IoT, big data, blockchain and other technologies, the amount of e-waste produced will increase. Therefore there is a need to create awareness on the benefits of proper recycling.

This study contributes to ongoing research on e-waste management in developing countries which has seen e-waste rising but with only a few handful studies conducted. Although the benefits of using second-hand ICT equipment have been enunciated, the government should establish stringent regulations and standards which can curb the illegal dumping of e-waste. This study's results can help policymakers and institutions formulate policies that can help manage e-waste effectively. Institutions can establish an integrated e-waste collection system by partnering NGOs and private entities in setting up e-waste recycling facilities and raise additional revenue for themselves. Institutions could also establish environmental management clubs that could drive e-waste awareness, collection and foster proper disposal. The implications of this research could lead to the introduction of multi-disciplinary environmental management courses across HEIs that promotes e-waste awareness. The study also recommends adopting sustainable practices such as recycling, reducing, repairing, and reuse.

REFERENCES

Agamuthu, P., & Dennis, V. (2013). Policy trends of e-waste management in Asia. *J. Mater. Cycles Waste Manage*, pp. 1–11. DOI:10.1007/s10163-013-0136-7

Agamuthu, P., Kasapo, P., & Nordin, N. (2015). E-waste flow among selected institutions of higher learning using material flow analysis model. *Resources, Conservation and Recycling*, *105*, 177–185. DOI:10.1016/j.resconrec.2015.09.018

Amankwah-Amoah, J. (2016). Global business and emerging economies: Towards a new perspective on. *Technological Forecasting & Social Change*, *105*, 20–26. DOI:10.1016/j.techfore.2016.01.026

Arif, N., & Afroz, R. (2014). Electrical and Electronic Waste Management–A Case Study at the University of Duhok, Iraq. *Journal of Economics and Sustainable Development*, *5*(1), 21-27. DOI: 10.25007/ajnu.v8n4a443

Azodo, P.A., Ogban, P., & Okpor, J. (2017). Knowledge and Awareness Implication on E-Waste Management among Nigerian Collegiate. *J. Appl. Sci. Environ. Manage.*, *21*(6), 1035-1040. DOI: 10.4314/jasem.v21i6.6

Babu, B., Parande, A., & Basha, C. (2007). Electrical and electronic waste: a global environmental problem. Waste Management & Research, *25*, 307-318. DOI: 10.1177/0734242X07076941

Bakhiyia, B., Gravela, S., Ceballos, D., Flynnd, M., & Zayeda, J. (2018). Has the question of e-waste opened a Pandora's box? An overview of unpredictable issues and challenges. *Environment International*, *110*, 173–192. DOI: 10.1016/j.envint.2017.10.021

Baldé, C., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). *The Global E-waste Monitor 2017*. Viena: ITU. Retrieved from https://www.itu.int/en/ITU-D/Environment/Pages/Toolbox/Global-E-waste-Monitor-2017.aspx

Baldé, C., Kuehr, R., & Blumenthal, K. (2015). E-waste statistics guidelines on classifications, reporting and indicators. *IAS – SCYCLE*. Retrieved from https://collections.unu.edu/view/UNU:6477

Borthakur, A., & Govind, M. (2018). Computer and mobile phone waste in urban India: an analysis from the perspectives of public perception, consumption and disposal behaviour. *Journal of Environmental Planning and Management*, pp. 1-24. DOI: 10.1080/09640568.2018.1429254

Chitotombe, W. (2013). Globalisation of Information Communication Technology (ICT) and consumerism in developing countries: Confronting the challenges of e-waste disposal in Harare urban, Zimbabwe. *International Journal of Environmental Sciences*, *3*(6), 2172-2185. DOI: 10.6088/ijes.2013030600033

Daum, K., Stoler, J., & Grant, R. (2017). Toward a more sustainable trajectory for e-waste policy: a review of a decade of e-waste research in Accra, Ghana. *International Journal of Environmental Research and Public Health*, *14*(135), 135- 150. DOI: 10.3390/ijerph14020135

de Oliveira, C., Bernardes, M., & Gerbase, E. (2012). Collection and Recycling of Electronic Scrap: A Worldwide Overview and Comparison with the Brazilian Situation. *Waste Management*, *32*(8), 1592–1610. DOI: 10.1016/j.wasman.2012.04.003

Debnatha, B., Roychoudhuri, R., & Ghosh, K. (2016). E-Waste Management – A Potential Route to Green Computing. *International Conference on Solid Waste Management, 5IconSWM*, *35*, 669–675. DOI: 10.1016/j.proenv.2016.07.063

Diaz, L., Lister, T., Parkman, J., & Clark, G. (2016). Comprehensive Process for the Recovery of Value and Critical Materials from Electronic Waste. *Journal of Cleaner Production*, *125*, 236–244. DOI: 10.1016/j.jclepro.2016.03.061

Digital Journal. (2016). *Minerals in e-waste discarded in 2016 were worth $65 billion.* Retrieved June 13, 2020, from http://www.digitaljournal.com/tech-and-science/technology: http://www.digitaljournal.com/tech-and-science/technology/the-minerals-in-e-waste-discarded-in-2016-was-worth-65-billion/article/509936

Edumadze, J., Tenkorang, Y., Armah, A., Luginaah, I., & Edumadze, E. (2013). Electronic Waste is a Mess: Awareness and Proenvironmental Behavior Among University Students in Ghana. *Applied Environmental Education & Communication*, *12*(4), 224-234. DOI:10.1080/1533015X.2013.876250

EMA. (2018). *Environmental regulations*. Retrieved from https://www.ema.co.zw/index.php/about-us/law/: https://www.ema.co.zw/index.php/about-us/law/environmental-regulations

Forti, V. (2020). *Global electronic waste up 21% in five years and recycling isn't keeping up*. Retrieved from https://www.weforum.org/agenda, Retrieved October 20, 2019, from https://www.weforum.org/agenda/2020/07/global-electronic-waste-recycling-management/

Gartner. (2015). *Gartner Says Smart Cities Will Use 1.1 Billion Connected Things in 2015.* New York City: Gartner. Retrieved May 12, 2020, from https://www.gartner.com/newsroom/id/3008917

Goleva, A., Schmeda-Lopez, D., Smart, K., Cordera, G., & McFarland, W. (2016). Where next on e-waste in Australia? *Waste Management*, *68*, 348-358. DOI:10.1016/j.wasman.2016.09.025

Gweme, F., Maringe, H., Ngoyi, L., & Stam, V. (2016). E-Waste in Zimbabwe and Zambia. *1st Institute of Lifelong Learning and Development Studies International Research Conference* (pp. 1-19). Chinhoyi. DOI:10.1016/J.RESCONREC.2015.09.018

Heeks, R., Subramanian, L., & Jones, C. (2015). Understanding e-Waste Management in Developing Countries: Strategies, Determinants, and Policy Implications in the Indian ICT Sector. *Information Technology for Development*, *21*(4), 653-667. DOI:10.1080/02681102.2014.886547

Hopson, E., & Puckett, J. (2016, May 30). *Scam Recycling: e-Dumping on Asia by US Recyclers. The e-Trash Transparency Project.* Retrieved June 10, 2019, from Basel Action Network: https://www.resource-recycling.com/images/BANReportTwo.pdf

Hossain, S., Sulala, M., Al-Hamadani, A., & Rahman, T. (2015). E-waste: A Challenge for Sustainable Development. *Journal of Health and Pollution*, *5*(9), 3-11. DOI:10.5696/2156-9614-5-9.3
Ikhlayel, M. (2018). An integrated approach to establish e-waste management systems for developing countries. *Journal of Cleaner Production*, *170*, 119-130. DOI:10.1016/j.jclepro.2017.09.137
Islam, M., Abdullah, A., Shahir, S., Kalam, M., Masjuki, H., Shumon, R., & Rashid, M. (2016). A Public Survey on Knowledge, Awareness, Attitude and Willingness to Pay for WEEE Management: Case Study in Bangladesh. *Journal of Cleaner Production*, *137*, 728-740. DOI:10.1016/j.jclepro.2016.07.111
Junghoon, M., Dulal, M., Hyoung, G. K., & Shin, J. (2012). An analysis of agricultural informatisation in Korea: the government's role in bridging the digital gap. *Information Development*, *28*(2), 102–116. DOI: 10.1177/0266666911432959
Khan, S., Lodhi, S., Akhtar, F., & Khokar, I. (2014). Challenges of waste of electric and electronic equipment (WEEE). *Management of Environmental Quality*, *25*(2), 166-185. DOI:10.1108/MEQ-12-2012-0077
Kumar, A., & Dixit. G. (2018). Evaluating critical barriers to implementation of WEEE management using DEMATEL approach. *Resources Conservation Recycling.*, *131*, 101–121. DOI: 10.1016/j.resconrec.2017.12.024
Luo, C., Liu, C., Wang, Y., Liu, X., Li, F., Zhang, G., & Li, X. (2011). Heavy metal contamination in soils and vegetables near an e-waste processing site, south China. *J. Hazard. Mater*, *186*, 481–490. DOI: 10.1016/j.jhazmat.2010.11.024
Makaramani, R. (2015). 21stCentury Learning Design for a Telecollaboration Project. *Social and Behavioral Sciences*, *191*, 622–627. DOI:10.1016/j.sbspro.2015.04.567
Maphosa, V. (2020). Using MyLSU app to enhance student engagement and promote a smart town at a rural university in Zimbabwe. *Cogent Education*, *7*(1), 1-16. DOI:10.1080/2331186X.2020.1823143
Maphosa, V., & Maphosa, M. (2020). E-waste management in Sub-Saharan Africa: A systematic literature review. *Cogent Business & Management*, *7*, 1-19. DOI:10.1080/23311975.2020.1814503
Mmereki, D., Li, B., Baldwin, A., & Hong, L. (2016). The Generation, Composition, Collection, Treatment and Disposal System, and Impact of E-Waste. In C. Mihai, *E-Waste in Transition - From Pollution to Resource* (pp. 65-93). DOI:10.5772/61332
Nganji, J., & Brayshaw, M. (2010). Is Green IT an Antidote to E-Waste Problems? *Innovation in Teaching and Learning in Information and Computer Sciences*, *9*(2), 1-9. DOI:10.11120/ital.2010.09020006
Nnorom, I., & Osibanjo, O. (2011, December 7-9). Measuring e-waste – results from country studies: Nigeria. *9th World Communication/ICT Indicator Meeting* (pp. 18-24). Mauritius. Retrieved from https://www.itu.int/ITU-D/ict/wtim11/index.html
Nwagwu, W., & Okuneye, M. (2016). (2016) Awareness and Attitudes of Small-Scale Information Technology Business Operators in Lagos, Nigeria Toward E-Waste Hazards. *Journal of Global Information Technology Management*, *19*(4), 267-282. DOI:10.1080/1097198X.2016.1246934
Ogbomo, M., Obuh, A., & Ibolo, E. (2012). Managing ICT waste: A case study of Delta State University, Abraka, Nigeria. *Library Philosophy and Practice*. Retrieved from https://digitalcommons.unl.edu/libphilprac/736/
Omobowale, A. (2012). Global e-waste management and second-hand consumption in the third world: Substandard context and Tokunbo phenomenon in Nigeria. *The Nigerian Journal of Sociology and Anthropology*, *10(2)*, 88–99. DOI:10.36108/NJSA/2102/01(0180)
Perkins, D., Drisse, B., Nxele, T., & Sly, P. (2014). E-waste: A Global Hazard. *Annals of Global Health*, *80*(4), 286–295. DOI:10.1016/j.aogh.2014.10.001
Ravi, V. (2015). Analysis of interactions among barriers of eco-efficiency in electronics packaging industry. *J. Cleaner Prod*, *101*, 16–25. DOI:10.1016/j.jclepro.2015.04.002

Reddy, R. (2016). Reimagining e-waste circuits: calculation, mobile policies, and the move to urban mining in Global South cities. *Urban Geography*, *37*(1), 57-76. DOI:10.1080/02723638.2015.1046710

Rochmana, F., Ashtona, W., & Wiharjoc, M. (2017). E-waste, money and power: Mapping electronic waste flows in Yogyakarta, Indonesia. *Environmental Development*, *24*, 1–8. DOI:10.1016/j.envdev.2017.02.002

Schumann, C., Baum, J., Forkel, E., Otto, F., & Reuther, K. (2017). Digital Transformation and Industry 4.0 as a Complex and Eclectic Change. *Future Technologies Conference (FTC) 2017* (pp. 645-650). Vancouver. Retrieved from https://saiconference.com/Conferences/FTC2017

Singh, N., Li, J., & Zeng, X. (2016). Global responses for recycling waste CRTs in e-waste. *Waste Management*, *57*, 187-197. DOI:10.1016/j.wasman.2016.03.013

Solomon, U. (2010). A detailed look at the three disciplines, environmental ethics, law and education to determine which plays the most critical role in environmental enhancement and protection. *Environ. Dev. Sustainability*, *12*(6), 1069–1080. DOI:10.1007/s10668-010-9242-z

Sthiannopkao, S., & Wong, M. (2013). Handling e-waste in developed and developing countries: Initiatives, practices, and consequences. *Science Total Environment*, *463*, 1147-1153. DOI: 10.1016/j.scitotenv.2012.06.088

Tran, C., & Salhofer, S. (2018). Analysis of recycling structures for e-waste in Vietnam. *Journal of Material Cycles and Waste Management*, pp. 110–126. DOI: 10.1007/s10163-016-0549-1

Tsan, K. (2015). A toxic legacy: E-waste recycling in Australia. *ReNew: Technology for a Sustainable Future*, (133), 54-55. Retrieved November 21, 2020, from https://www.jstor.org/stable/renetechsustfutu.133.54

TUM. (2020, July 16). *Sustainable e-waste management: Successful cooperation of TUM and Ghanaian university*. Retrieved from September 13, 2020, from https://www.cs.tum.de/sustainable-e-waste-management-successful-cooperation-of-tumcs-and-ghanaian-university/?lang=en

Wang, W., Tian, Y., Zhu, Q., & Zhong, Y. (2017). Barriers for household e-waste collection in China: Perspectives from formal collecting enterprises in Liaoning Province. *Journal of Cleaner Production*, *153*, 299-308. DOI:10.1016/j.jclepro.2017.03.202

Yu, J., Williams, E., Ju, M., & Yang, Y. (2010). Forecasting Global Generation of Obsolete Personal Computers. *Environment Science Technology*, *44*(9), 3232-3237. DOI:10.1021/es903350q