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Article

E-waste management in Sub-Saharan Africa: A systematic literature review

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OPERATIONS, INFORMATION & TECHNOLOGY | REVIEW ARTICLE

E-waste management in Sub-Saharan Africa: A systematic literature review

Vusumuzi Maphosa^{1*} and Mfowabo Maphosa²

Abstract: The developing world has become the primary destination for used electrical and electronic equipment (EEE) exported by the developed world, making e-waste management critical. This paper aims to determine the state of e-waste management in Sub-Saharan Africa by critically reviewing the corpus on electronic waste (e-waste) management in the region. Even though many studies were conducted on e-waste management, very few are conducted on developing countries who are significant recipients of used EEE. We applied a systematic literature review (SLR) process on research articles retrieved from Web of Science, EBSCO Host and Sabinet databases. Using the keywords that included e-waste management or recycling or policy in Sub-Saharan Africa or Africa, we searched for articles from these databases. We analysed 25 papers selected from 151,558 papers initially retrieved to answer the research questions. The findings revealed that about 80% of research on e-waste management in the Sub-Saharan Africa region was undertaken in three countries: Ghana, Nigeria, and South Africa. The review of the selected articles revealed that lack of policy and limited recycling infrastructure were the main barriers to effective e-waste management. The SLR revealed that most

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Vusumuzi Maphosa holds a doctoral degree in Information Systems and Technology. He has extensive experience in leading knowledge management and ICT based interventions in public, private and voluntary based organisations. His research interests are on transformative concepts and technologies that include ICT4D, Industry 4.0, data mining, IoT and smarties, semantic webs and ontologies and e-governance. He has published and presented papers at national and international conferences. This research is part of a wider ICT4D project.

PUBLIC INTEREST STATEMENT

In an attempt to bridge the digital divide, developing countries have become significant recipients of second-hand electrical and electronic equipment. We applied a systematic literature review process on research articles published between 2008 –2020 to examine the state of e-waste in Sub-Saharan Africa. Over 80% of the research articles focused on Ghana, Nigeria and South Africa. Research on e-waste management in Sub-Saharan Africa is gaining traction as 68% of the articles were published in the last five years. The results show that most countries did not have specific policies on e-waste but relied on hazardous waste policies. Dumping and improper recycling of e-waste cause problems such as contamination of soils, water, and depletion of grazing land, health problems - respiratory infections, various cancers, congenital disabilities, damage to the brain and other vital organs. E-waste workers earn more than any other informal workers. African governments and policymakers must enact laws that govern e-waste management and collaborate with development agencies in educating communities on e-waste management.

countries in the region practice informal and rudimentary recycling methods. Based on the common barriers identified, our recommendations can provide insight to policymakers, contribute to theory, and offer opportunities for future research.

Subjects: Environment & Health; Environmental Policy; Management of IT; Computer Science; General

Keywords: e-waste; e-waste management; recycling; environment; policy; landfills; health

1. Introduction

The attainment of most of the Sustainable Development Goals (SDGs) hinges on a digitally connected world (Orisakwe et al., 2019; Oteng-Ababio et al., 2020; Schroeder et al., 2019). As the world transformed into a global village, the knowledge economy emerged with more dependence on electrical and electronic equipment (EEE) (Ssewanyana & Busler, 2007). The demand for EEE has risen astronomically due to consumer demand for new products. Kumar and Dixit (2018) noted that the rapid technological advancement and the quest for more profitability by firms resulted in the faster introduction of newer and cheaper products. In contrast, the lifespan of EEE has shortened, thus resulting in their discarding even before reaching their useful lifespan. Many countries in Africa depend on refurbished computers from developed countries to participate in the knowledge economy. However, failure to manage obsolete and unrepairable EEE results in electronic waste (e-waste), whose increase is detrimental to the environment and human health. E-waste refers to obsolete and abandoned EEE containing toxic substances that are generally disposed of in illegal dumpsites in most developing countries (Nwagwu & Okuneye, 2016).

The objective of this paper is to provide an overview of e-waste management in Sub-Saharan Africa. At present, general research on e-waste management in developing countries is still in its infancy. This review examined 25 articles on e-waste management in the region selected through a rigorous process involving bibliometric and content analysis. We discuss e-waste management issues affecting most African countries such as lack of awareness, policy, infrastructure, the effect on public health and the environment as well as livelihood issues. The paper also highlights that the idea of importing used EEE to bridge the digital divide in the Global South is noble, but ought to be done in the presence of sound policies that can deter illegal dumping and subsistence recycling of e-waste. Existing literature shows that many countries in the Sub-Saharan Africa region do not have policies to manage e-waste. This paper contributes to the literature on e-governance by reviewing existing literature on e-waste management in Sub-Saharan Africa.

This analysis reveals the status of e-waste and summarises issues that have an influence on policy and practice on e-waste management in Sub-Saharan Africa. The study denotes the current e-waste management and recycling methods practised in most countries in this region and how they relate to environmental sustainability and human health. The remaining sections of this paper are the literature review, methodology, presentation of the main review findings, discussion, limitations and conclusions, and direction for future research.

2. Literature review

The advent of the knowledge economy has put immense pressure on the developing world to embrace digital technologies to join the global village. The rapid modernisation, industrialisation and consumer appetite for better products has exacerbated e-waste management challenges. The lifespan of computers and peripherals reduced from 5–10 years previously and now ranges between 3–4 years as this equipment is built with a focus on replacement instead of repairing (Agamuthu et al., 2015). Omobowale (2012) asserted that poor communities in developing countries only afford second-hand EEE. Additionally, Orisakwe et al. (2019) noted that second-hand EEE

allowed those who were marginalised to have access to information related to markets and prices, promoting sustainable development.

Wang et al. (2013) postulate that developed countries had enacted policies, infrastructure, and technical skills to manage e-waste. Developed countries embraced the Extended Producer Responsibility (EPR) policy which places the burden of managing e-waste in the hands of the manufacturers of EEE (Fraige et al., 2012). The EPR adopted by most developed countries allows consumers to return obsolete EEE to the manufacturers for a fee paid to the consumer (Adanu et al., 2020; Cahill et al., 2011). In developed countries such as United States, Japan, Germany, Sweden, and Switzerland and others, e-waste collection and recycling is coordinated by producers and municipalities through effective policies (Mmereki et al., 2015). China established over 109 formal recycling centres which have collected over 43 million units beyond the country's recycling needs (Ghosh et al., 2016).

Though the Global North has developed policies and set up the infrastructure to recycle e-waste, it remains lucrative to ship it to the Global South, where there are no policies and legislation to govern its management. Worryingly, the recipient countries lack policies, knowledge, and appropriate disposal facilities, thus resulting in the accumulation of e-waste (Nganji & Brayshaw, 2010). Orisakwe et al. (2019) noted that recipient countries had no policies and infrastructure to handle e-waste, therefore posing a danger to the environment and human health. Developing nations face unprecedented strain on the environment and human health as global e-waste output is likely to exceed 53 million metric tonnes by 2021 (Baldé et al., 2017). Developing nations' domestic e-waste was 25.4 million tons, and for the first time, it exceeded that of the developed world's domestic e-waste that stood at 23.5 million tons (Collins, 2013). By 2030, the developing world will dispose of over 700 million obsolete computers, yet few studies on e-waste management were conducted in Africa (Kumar & Dixit, 2018; Sthiannopkao & Wong, 2013).

The detrimental effect of improper handling of e-waste on the environment and human life made developed countries enact policies that govern e-waste management (Khan et al., 2014). In most developing countries, e-waste handlers use rudimentary means of processing e-waste through incinerating or open burning in dumpsites. The most affected and vulnerable groups are; the illegal e-waste workers who use rudimentary means, with no appropriate tools, the general public which reside near informal recycling dumpsites, children and pregnant women (Bakhiyi et al., 2018).

There have been reports of illegal transboundary movement of hazardous waste from the Global North disguised as commercial goods to developing countries (Amankwah-Amoah, 2016; Hopson & Puckett, 2016). About 80% of the e-waste produced by the Global North was exported illegally to developing countries in the Global South (Yu et al., 2017). Doyon-Martin (2015) have reported an increase in intra-African e-waste movement from countries such as South Africa, Nigeria, and Tunisia to other countries with porous borders such as the Democratic Republic of Congo, Zimbabwe, and Mozambique among others. Although e-waste contains toxic and hazardous metals such as barium and mercury among others, it also contains non-ferrous metals such as copper, aluminium and precious metals such as gold and copper, which if recycled could earn income over 55 billion euros (Baldé et al., 2017; Peluola, 2016).

Despite the evident e-waste disaster, most developing countries do not have legislation and appropriate infrastructure, so e-waste is handled by illegal recyclers who pollute the environment and threaten public health (Arif & Afroz, 2014). Scholars have posited that there is little information on the volume of e-waste in developing countries who often do not have systems to deal with e-waste (Mmereki et al., 2015; Orisakwe et al., 2019). South Africa, Rwanda, and Uganda are some of the countries in the Sub-Saharan Africa region that have taken many steps in managing e-waste through enacting various policies and laws (Baldé et al., 2017). There is a need for more developing countries to enact policies that guide the management of e-waste to prevent environmental

degradation and adverse effects on human health (de Oliveira et al., 2012; Orisakwe et al., 2019). Limited research and a lack of national effort in managing e-waste in most developing countries are the causes for the unavailability on information on e-waste volumes generated in these countries.

Little work has been carried out on e-waste management in developing countries and previous works have not comprehensively considered Africa or the Sub-Saharan Africa in particular. The paper aims to provide an overview of the state of e-waste management in the Sub-Saharan Africa region which has become a significant recipient of second-hand EEE in an attempt to bridge the digital divide and join the information super high way. The SLR will provide a knowledge map that shows research trends in the region. The study proposed two research questions:

- i. What is the state of e-waste management in Sub-Saharan Africa?*
- ii. What are the significant challenges regarding e-waste management in the region?*

3. Methodology

Kitchenham (2004) proposed the SLR as a critical step in conducting scientific research. This method involves analysing all relevant primary research publications by identifying, mapping, evaluating, aggregating and interpreting based on a particular research question, phenomenon of interest or topic area. Also, SLR is used to identify gaps in particular topics to be filled. The SLR analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Kitchenham et al., 2009), which is in line with the aim of SLR, which is to construct a broader view of the research question by summarising the literature with minimum bias (Kitchenham, 2004). In response to the research questions, we conducted a systematic literature search in February 2020 on relevant scientific journals. To narrow down the search and acquire relevant content, we considered papers published between January 2008 and January 2020. To broaden the article base and produce a comprehensive search, we used the top bibliographic databases for conducting the search process. Based on the accessibility of articles, we chose the following scientific databases: Web of Science (Taylor and Francis Online, Science Direct, Sage, Springer Link), EBSCO Host and Sabinet African Journals. Due to the nature of the study, we included Sabinet African Journals because they publish articles originating from or about Africa. We utilised keywords used in most e-waste management literature in developing countries, including their synonyms, to find suitable research articles.

Kitchenham and Charters (2007) proposed that Boolean operators (“AND” and “OR”) be used as well as applying their different combinations to refine the search string. For this study, we used the logical operator “OR” to join the identified keywords, and we used the “AND” operator to combine the keywords in the phrase. The initial search string included the keywords (“e-waste” OR “e-waste management” OR “disposal” OR “policy” OR “recycling infrastructure”) AND (“Africa” OR “Sub-Saharan Africa” OR “developing countries”). The Boolean operators optimised the searches through the retrieval of the top-ranked publications based on the search string. The search strategy did not consider any “grey literature” or white papers as there was adequate referenced literature, as shown in Figure 1. We utilised a four-stage exhaustive search strategy, as shown in Table 1.

The search string used gave an exhaustive and comprehensive picture of e-waste management in Sub-Saharan Africa. The search targeted the title, abstract, and keywords used in the article. In the first stage, we applied the refined search string targeting the selected databases yielding 151, 558 research articles, as shown in Figure 1. The search contained a variety of publications from refereed journals to newspaper articles and student articles with much irrelevant text. We excluded many research articles retrieved as they did not cover any aspect related to e-waste as well as research articles that majored on solid and municipal waste.

In the second stage, we further refined the search string to increase the accuracy of the searches by using the search string (“e-waste” OR “e-waste management”) AND (“Africa” OR “Sub-Saharan

Figure 1. Article selection process.

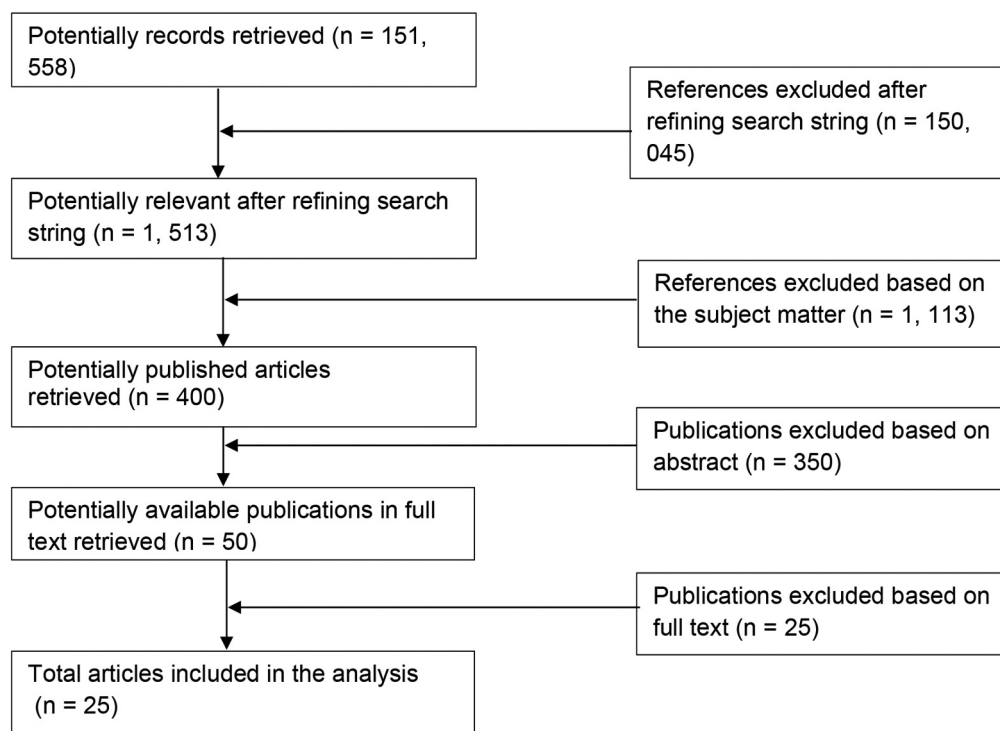


Table 1. Iterative search for article selection

	1 st search	2 nd search	3 rd search	Final search
Francis and Taylor*	90435	211	103	3
Science Direct**	3603	668	52	2
Springer*	2800	185	140	3
Sage*	26330	120	34	7
EBSCO	27692	68	59	8
Sabinet	698	261	12	2
Total	151 558	1 513	400	25

*Database under Web of Science Group

**Database under Web of Science Group and SCOPUS

Africa”) and this produced better results. We examined all the research article by title yielding to 1, 513 papers. In the next phase, we retained 400 research articles after examining each publication title to make sure that it specifically related to e-waste in Africa or sub-Saharan Africa.

In the fourth phase, we evaluated the selected papers to ensure that they related to e-waste management, awareness, policy, and recycling infrastructure in Sub-Saharan Africa and this resulted in the further exclusion of 350 papers. We used Rayyan (<https://rayyan.qcri.org>), a free web and mobile app for conducting systematic reviews for screening the articles. Rayyan is used to speed up the initial abstract/title screening of articles, and it allows researchers to collaborate in reviews (Ouzzani et al., 2016). We uploaded citation files downloaded from the databases scientific databases. For the study, the authors collaborated and screened the articles individually. We used the three labels “include”, “exclude” and “undecided”. In cases where an article was labelled as undecided, by either author, we discussed the article before labelling it as included or excluded.

The final iterative search stage involved identifying candidate articles. We determined the relevancy of the full article by carefully reading the abstract and the conclusion. We included the identified research articles on the final list based on the degree to which they answered the research questions. Finally, we also examined duplicate titles and leaving 25 most relevant papers. Appendix A shows the list of the papers chosen for the study.

Content analysis was performed to extract emerging themes from the selected papers. Extracted data were then classified to address the research questions. The articles provided information on the country, the focus of the study and how data was analysed. We, therefore, applied content analysis to provide a summary of extracted data in line with assertions by Mayring (2000) who concluded that data evaluation involves text comprehension and interpretation. The main variables are discussed as emerging themes (Section 4.2) show the state of e-waste management in the Sub-Saharan Africa region. We used the emerging themes to identify trends and gaps in e-waste management corpus in the region. The data was then analysed quantitatively and qualitatively to interpret the underlying terms and arguments.

4. Results

In this section, we report the results of our study, where we answer our research questions and discuss the findings from the extracted data. To analyse the data, we used qualitative and quantitative methods to explain the emerging themes from the selected articles. Figure 2 shows a screenshot of the themes, topics and countries covered by the 25 articles selected for final analysis using Rayyan. The higher the frequency of the topic, themes and countries in the study, the bigger the font size as depicted by Rayyan in Figure 2. To access articles covering a particular topic, theme or country, we clicked on the hyperlinks.

4.1. The state of e-waste management in Sub-Saharan Africa

4.1.1. Distribution of papers by country

The analysis of the selected 25 papers showed that 20 specifically focused on four African countries, while three covered the rest of the continent in general. Figure 3 highlights the distribution of the articles by country. A total of 10 papers (40%) focused on Ghana while Nigeria followed with seven papers (28%), South Africa with three papers (12%), and Botswana with one (4%) with the remaining three (12%) focusing on African countries in

Figure 2. Themes, topics and countries covered in the research articles.



Figure 3. Selected articles by country.

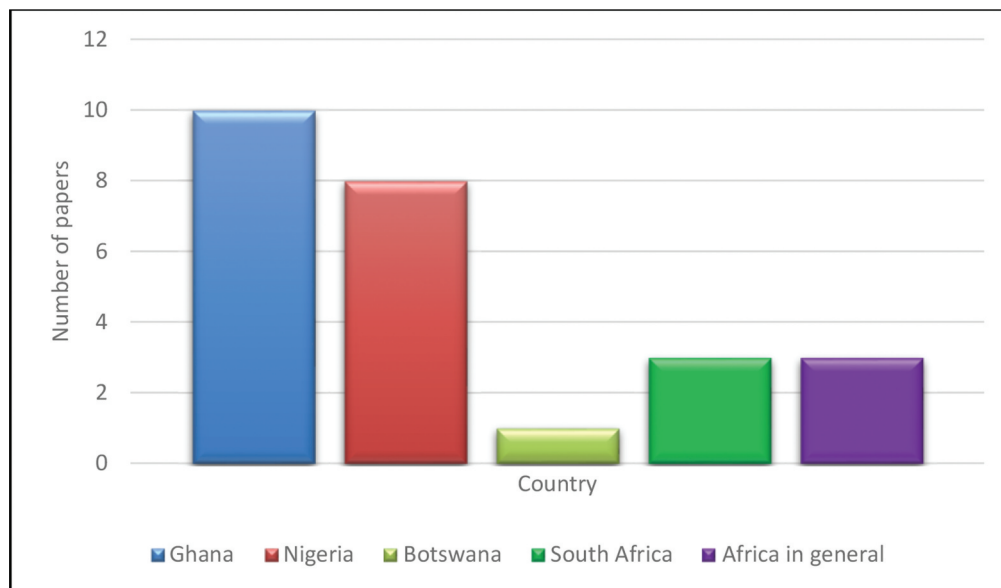
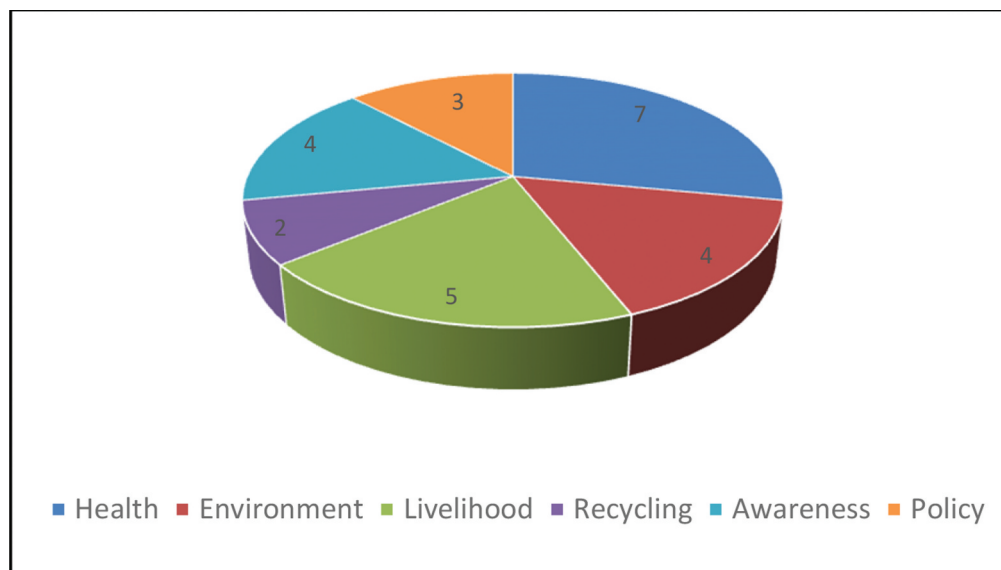


Figure 4. Distribution of papers by thematic area.



general. The three most researched countries account for 80% of the articles in the final inclusion, and this shows that e-waste management issues are topical and have been well researched in these countries.

4.1.2. Distribution of papers by category

From the selected 25 articles, seven articles majored on the impact of e-waste on health and five tackled the impact of e-waste on people's livelihood. Four articles investigated e-waste and the environment, two researched the willingness to recycle, four examined on awareness, and the last three probed e-waste policy and legislation as shown in figure 4. It must be noted that most of these six main issues were also generally captured across all the publications as they are inter-linked in the effective management of e-waste.

4.1.3. Distribution of papers by year

The first eight years (2008–2015), saw 32% of the papers being published and this low research indicates that e-waste management issues had not yet gained substantial appreciation while the last years (2016–January 2020) accounted for 68% of the published articles. The increase in the years 2016–2020 shows that research on e-waste management in Sub-Saharan Africa is gaining traction.

In the last decade, only three African countries amended their environmental laws to include e-waste: South Africa with the National Environmental Management Waste Amendment Act, 26 of 2014 (Ghosh et al., 2016); Nigeria implemented the National Environmental Regulations S.I.23 of 2011 (Okorhi et al., 2019) and Ghana drafted its e-waste management through the support of the Basel Convention in 2012 (Tetteh & Lengel, 2017).

The first research question for the study was to ascertain the state of e-waste management in Sub-Saharan Africa. The findings show that research on e-waste management in Sub-Saharan Africa is still in its infancy stage with two countries dominating research. What is encouraging is the increase in the number of research articles that were published between 2016 and January 2020. The volume of e-waste is accumulating, yet research that can influence policy-makers and governments to consider taking appropriate steps to manage e-waste is lacking. The fact that only 8.6% of reviewed articles were published in the Sabinet African Journals shows that there is need for African journals to promote emerging areas for more research such as e-waste and promote research work by African scholars.

4.2. Interpreting findings

The volume of e-waste in developing countries is accumulating at an alarming rate (Mmereki et al., 2015). In Ghana, a monthly average of about 600 containers which are approximately 40-foot dock to offload e-waste (Amuzu, 2018). This was corroborated by Grant and Oteng-Ababio (2016) who highlighted that over 600 40-foot containers arrive at the port of Tema, feeding a complex e-waste market with an estimated 13,000 tons of e-waste processed annually. E-waste imported into Nigeria annually was approximately 400,000 tons (Nwagwu & Okuneye, 2016). The Nigerian port of Lagos is receiving over 100 000 used computers monthly (Okorhi et al., 2019). E-waste generated in South Africa was about 64,000 tons, with about 11% formally recycled (Machete, 2017). The following subsections will discuss the themes that emerged from the analysis of the reviewed papers.

4.2.1. Human health

The impact of e-waste on human health has been devastating. Communities near e-waste recycling sites are prone to health and safety concerns such as inhalation of toxic chemicals and exposure to radiation (Jibiri et al., 2014). A study by Machete (2017) in South Africa confirmed human exposure to toxic metals such as arsenic, mercury, and cadmium whose effect on human health is catastrophic. Umesi and Onyia (2008) highlighted that e-waste contained an array of toxic materials such as lead, mercury, barium, and beryllium. The burning of e-waste in open dumpsites causes the release of organic pollutants that affect human health (Ogungbuyi et al., 2012). A study in Ghana showed that pollutants released during burning trigger respiratory infections, eye irritation, and asthma, among others (Acquah et al., 2019; Umesi & Onyia, 2008). In a similar study, Asampong et al. (2015) noted that e-waste workers reported acute respiratory infections and chest pains; Peluola (2016) also established that workers who dismantled EEE had skin and eye irritation while others complained of persistent coughing. This is supported by a survey by Peluola (2016), who revealed that e-waste workers were at risk of absorbing hazardous substances through their skin as well as smoke inhalation. Lambrechts (2016) and Nnorom and Osibanjo (2011) also observed that e-waste recyclers used rudimentary and crude ways such as burning to recover useful parts without due care on the effect on their health. Adanu et al. (2020) found that e-waste workers used stones, hammers and banging e-waste items on the ground to separate components. Acquah et al. (2019) corroborated that e-waste workers relied on inefficient tools such as hammers and chisels, which led to musculoskeletal injuries.

Adanu et al. (2020) reports that e-waste workers at the Agbogbloshie use their bare hands to sort, burn and salvaging useful items from e-waste. A study by Burns et al. (2019) confirmed that e-waste workers experienced lacerations to their hands due to manual processes during recycling. Yu et al. (2017) and Burns et al. (2019) provided evidence that e-waste workers experienced body pain, hearing loss, cuts, and coughs. Tetteh and Lengel (2017) revealed that unregulated e-waste recycling led to the release of hazardous materials that polluted the environment leading to a rise in cancerous diseases among dumpsite workers and those within the vicinity. Another study by Agyei-Mensah and De-graft Aikins (2010) concluded that about 50% of e-waste workers suffered chest pains and respiratory infections while others contracted various cancers. Olafisoye et al. (2013) and Amuzu (2018) reiterated that exposure to hazardous metals damaged the nervous system, decreased mental capacity, and caused blood disorders. According to Acquah et al. (2019), e-waste workers end up addicted to some drugs to manage the pain leading to drug resistance. Research conducted in Nigeria revealed that e-waste had caused congenital disabilities and infant mortality, damage to the brain, and other vital organs as well as respiratory, stomach, and skin infections (Nwagwu & Okuneye, 2016).

4.2.2. Landfills

Developing countries resort to unregulated recycling that use manual processes to reclaim precious metals found in e-waste, these activities damage the environment through acid leaching and open burning, causing landfills and dumpsites to be the most polluted sites (Tetteh & Lengel, 2017; Velis, 2017). Ghana's Agbogbloshie is one of the biggest landfills in the world, which covers over 20 acres, where crude and manual recycling takes place (Lambrechts, 2016). The Agbogbloshie receives over 15% of the global e-waste where informal recycling is done, releasing lead, mercury, and zinc into the environment making the site the world's most toxic (Boaten, 2011). South Africa's landfills in Badplass, Carolina, and Elukwatini have recorded high volumes of arsenic, lead, mercury, and cadmium, threatening the environment, and human life (Machete, 2017). Nigeria's Alaba is one of the largest dumpsites in West Africa, where recyclers burn and use crude recycling practices to recover useful parts (Jibiri et al., 2014). Ogunbuyi et al. (2012) reported that e-waste was being burnt in open sites in Nigeria, releasing pollutants that destroy the environment and human health. In their study, Olafisoye et al. (2013) found that 75% of heavy metals found in landfills emanated from e-waste.

4.2.3. Recycling

Yu et al. (2017) revealed that recyclers in most African countries lacked recycling facilities and resorted to dismantling, burning, and acid leaching to recover precious metals. To recover precious metals in e-waste, Umesi and Onyia (2008) reported that recyclers resorted to manual and labour-intensive processes; this was supported by Peluola (2016) who observed that recyclers resorted to dismantling and leaching of precious metals. In one study, over 71% of respondents reported that the Nigerian government had not yet build recycling facilities to treat e-waste (Okorhi et al., 2019). Isimekhai et al. (2017) reported that e-waste recyclers at the Alaba, Nigeria recovered precious metals such as copper and aluminium through manual dismantling and burning of EEE. The Agbogbloshie, in Ghana, is one of the world's most polluted sites where crude and rudimentary methods such as manual dismantling and burning are used to recover precious metals (Kyere et al., 2017). Similarly recycle workers at the Alaba dumpsite in Nigeria use crude methods such as burning to retrieve precious metals and re-usable components (Jibiri et al., 2014). Grant and Oteng-Ababio (2016) noted that South Africa was the only country in Sub-Saharan Africa that operated a formal recycling plant. Lawhon (2013) reported that recyclers in Cape Town enhanced profitability by exporting PC boards to Europe for high-tech recycling.

4.2.4. Environment

Hundreds of tons of shipments of used EEE are exported to African countries to bridge the digital divide, but most of it is e-waste which ends up being burned in landfills thereby polluting the environment (Umesi & Onyia, 2008). Scholars noted that e-waste recyclers in Africa lack the know-how and infrastructure and resort to the open burning of e-waste leading to the discharge of hazardous materials that damage the environment and human health (Nnorom & Osibanjo, 2011; Olafisoye et al., 2013). Most countries resort to open burning and incineration, to reduce e-waste

accumulation, leading to environmental degradation (Agyei-Mensah & De-graft Aikins, 2010). Yu et al. (2017) and Isimekhai et al. (2017) concluded that informal e-waste recycling and disposal in Sub-Saharan Africa led to the release of environmental contaminants that threatened living organisms. Improper handling of e-waste through the burning of monitors and cables lead to the release of harmful substances into the soil (Peluala, 2016). Lambrechts (2016) noted that most African countries did not have the knowledge to manage e-waste and therefore resort to dumping, which further leads to environmental degradation. In Ghana, improper e-waste recycling has led to contamination of the soil and rivers through the release of toxins from lead, mercury, arsenic among others affecting the Agbogbloshie's informal workers and nearby communities (Amuzu, 2018; Srigboh et al., 2016). Lambrechts (2016) concurred that to recover precious materials, improper e-waste handling resulted in crude recycling practices that threatened the environment. Another study revealed that improper e-waste recycling led to exposure to hazardous metals such as arsenic, lead, mercury, and cadmium which affected the environment and public health (Machete, 2017). A study conducted by Olafisoye et al. (2013) revealed that e-waste contributed more than 75% of heavy metals such as Polyvinyl Chloride (PVC) and brominated flame-retardants found in landfills which pollute the environment. All these studies highlight how a lack of proper e-waste handling is affecting the environment.

4.2.5. Lack of policies

One of the significant challenges to e-waste management in the Sub-Saharan Africa region is the lack of specific policies, as current policies in most countries deal with general hazardous waste and cannot curb illegal importation and recycling of e-waste. Lambrechts (2016) noted that the Basel Convention had reported that African countries had policies that covered general hazardous waste, and none had enacted laws that deal with e-waste. Olafisoye et al. (2013) noted that many countries did not have specific e-waste policies, and this has led to the continuous discharge of toxic materials into the environment. Development of firm policies and the use of efficient technologies have been described as critical in e-waste management (Adanu et al., 2020). Tetteh and Lengel (2017) concurred that in most African countries, there was no coordination between various ministries to deal with e-waste. This was corroborated by Mmereki et al. (2015) who observed that lack of specific e-waste policies in Botswana made it challenging to coordinate e-waste management roles and responsibilities. The harmful Waste Act HI 2004 in Nigeria banned the importation of hazardous waste but has failed to stop the thriving e-waste import business in the country (Nwagwu & Okuneye, 2016). Umesi and Onyia (2008) reiterated that Nigerian laws did not address e-waste disposal; Okorhi et al. (2019) highlighted that e-waste management in Nigeria was based on any combination of the four existing laws; the Harmful Waste Act HI 2004; the National Environmental Protection Regulations S.I.15 of 1991; the National Environmental Regulation S.I.28 of 2008 and the National Environmental Regulations S.I.23 of 2011.

In 2016, Ghana passed Act 917 to support e-waste management efforts, but there has been little improvement (Oteng-Ababio et al., 2020). Ineffective implementation of e-waste policies makes it easy for an average of 600 40-foot long containers to dock and offload e-waste every month in Ghana (Amuzu, 2018). This has seen Ghana's Agbogbloshie becoming the biggest and one of the most notorious and polluted e-waste facility in the world (Burns et al., 2019; Srigboh et al., 2016). Bob et al. (2017) observed that South Africa did not have e-waste policies but relied on various legislation that covered the management of hazardous waste. Tetteh and Lengel (2017) argued that the country was leading with regards to effective e-waste management in Africa through its National Environment Management Act 107 of 1998, which recommends re-use, refurbish and proper e-waste management.

4.2.6. E-waste and livelihoods

E-waste recycling is a 55-billion-euro industry, and if proper policies and infrastructure are in place, the developing world could have a considerable stake in the recovery of precious metals such as gold and copper (Baldé et al., 2017; Peluala, 2016). Despite the economic potential, e-waste workers earn meagre incomes because of the use of archaic manual tools such as hammers and chisels (Acquah et al., 2019). It was reported that the Agbogbloshie site in Ghana was responsible for refurbishing at least 25% of computers donated to schools, earning workers a reasonable income to meet their basic needs as well as support distant relatives (Amuzu, 2018). Lambrechts (2016) noted that more than 30,000 e-waste

recyclers earned their income from recycling and also contributed to Nigeria's GDP; Grant and Oteng-Ababio (2016) estimated that the Agbogbloshie site directly employed over 15,000 workers; Asampong et al. (2015) concurred that informal workers in Ghana recovered gold, copper, silver among other metals from e-waste which they sold for their livelihood. Central to the e-waste value chain are the collectors who earn an average of USD3.50 per day, this is competitive compared to USD1.40 which is earned by other informal workers in Ghana (Grant & Oteng-Ababio, 2016). In a similar study, Acquah et al. (2019) noted that e-waste recyclers in Ghana earned about USD10.00 per week.

5. Discussion

The first research question of the study sought to provide an overview of the state of e-waste management in Sub-Saharan Africa. The results revealed the state of e-waste management in the region, with 80% of the research conducted in Ghana, Nigeria and South Africa. The volume of e-waste is increasing at an alarming rate, yet most countries do not have policies and infrastructure to handle e-waste. In answering the second research question, the study identified the significant challenges regarding e-waste. The findings revealed that the lack of policy and limited recycling infrastructure are some of the main barriers to effective e-waste management. Results reveal that most Sub-Saharan African countries had no recycling facilities and resorted to dismantling, burning, and acid leaching to recover precious metals. Informal and rudimentary methods are prevalent such as the use of stones, hammers and chisels to separate components. E-waste is dumped in landfills such as the Agbogbloshie, Alaba and Elukwatini and has recorded high volumes of toxic chemicals. The impact of e-waste on human health has been devastating to communities near e-waste landfills which are prone to contracting various respiratory and skin diseases and contract various cancers. Controlling the informal e-waste market will prove challenging as studies revealed that e-waste workers earn more than other informal workers. We did not find any SLR that was done across a block such as the Sub-Saharan region. Our findings are similar to those of a study in India which established that lack of formal recycling, absence of policies and inappropriate handling were threatening e-waste management efforts (Heeks et al., 2015). Schroeder et al. (2019) reported that over 95% of e-waste was treated in slums in India, without protective equipment, thereby exposing workers to dangerous chemicals. These findings were corroborated by Orisakwe et al. (2019) concluded that e-waste posed human health and environmental risks in Africa, where there were inadequate policies and infrastructure to recycle and dispose of safely.

6. Conclusion and future work

In this paper, we provided an overview of the state of e-waste management in Sub-Saharan Africa, and we identified the significant challenges to e-waste management in the region. In an attempt to bridge the digital divide, developing countries have allowed the importation of used EEE, and this has resulted in extensive dumping of e-waste disguised as re-usable EEE. The article identified the main trends and gaps in e-waste management in developing countries such as lack of policies, awareness, and infrastructure. No country in Sub-Saharan Africa has specific laws that govern e-waste, and most rely on legislation that regulates hazardous waste. Most recycling is done informally using primitive methods to recover precious metals without considering the colossal damage on the environment and human health. The paper did spell out the economic benefits of e-waste; African governments must enact laws that allow e-waste recyclers to extract precious metals in an environmentally sustainable manner.

The selected databases do not cover all the top articles as most are accessible through paying substantive amounts of money in subscriptions; this may have limited the quality of selected papers. As we filtered research papers published between 2008-January 2020, we could have excluded some good papers. The search keywords may not have been exhaustive; thus, we could have missed some articles. Though the study covered the Sub-Saharan region, Ghana accounted for 40%, Nigeria with 28%, and South Africa accounted for 12% of the available literature, which may bring some bias.

In our paper, we make contributions to policymakers and the knowledge frontier. For policymakers, the paper stated the effect of e-waste, its management thereof, and how barriers to effective e-waste management could be handled. Governments and development agencies should collaborate and avail resources to educate and empower e-waste workers on human health and environmental protection. This SLR presents an overview of e-waste research in the region and make scholarly contributions in the field and provides a knowledge map that shows research trends and directions for future research in the field. Other researchers can benefit from this paper, by using it as a basis for future research, particularly, lack of research on e-waste management in Sub-Saharan Africa that covers most of the countries. Future research can also focus on how e-waste management successes in the Global North could be adapted in the Global South, particularly in the Sub-Saharan Africa region.

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Appendix

No.	Database	Journal	Author/(s)	Title of Paper	Country
1	EBSCO	Journal of Global Information Technology Management	Nwagwu and Okuneye (2016)	Awareness and Attitudes of Small-Scale Information Technology Business Operators in Lagos, Nigeria Toward E-Waste Hazards	Nigeria
2	EBSCO	Politikon: South African Journal of Political Studies	Lambrechts, 2016	Environmental Organised Crime: The Dirty Business of Hazardous Waste Disposal and Limited State Capacity in Africa	Africa in general
3	EBSCO	Polish Journal of Environmental Studies	Olafisoye et al. (2013)	Heavy Metals Contamination of Water, Soil, and Plants around an Electronic Waste Dumpsite	Nigeria
4	EBSCO	Chemosphere	Srigboh et al. (2016)	Multiple elemental exposures amongst workers at the Agbogbloshie electronic waste (e-waste) site in Ghana	Ghana
5	EBSCO	International Journal of Environmental Health Research	Agyei-Mensah and Oteng-Ababio (2012)	Perceptions of health and environmental impacts of e-waste management in Ghana	Ghana
6	EBSCO	Environmental Health & Toxicology	Kyere et al. (2017)	Spatial assessment of potential ecological risk of heavy metals in soils from informal e-waste recycling in Ghana	Ghana
7	SABINET	African Journal of Science, Technology, Innovation & Development	Okorhi et al. (2019)	Disconnect between policy and practice in developing countries: Evidence of managing e-waste from Nigeria	Nigeria
8	SABINET	African Journal of Science, Technology, Innovation & Development	Machete (2017)	Environmental health risks associated with e-waste exposure in Badplaas, Carolina and Elukwatini landfills, Republic of South Africa	South Africa
9	EBSCO	New African	Boaten (2011)	Ghana burns its health away	Ghana

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No.	Database	Journal	Author/(s)	Title of Paper	Country
10	EBSCO	Africa Today	Grant and Oteng-Ababio (2016)	The Global Transformation of Materials and the Emergence of Informal Urban Mining in Accra, Ghana	Ghana
11	TAYLOR AND FRANCIS	International Journal of Sustainable Development & World Ecology	Umesi and Onyia (2008)	Disposal of e-wastes in Nigeria: an appraisal of regulations and current practices	Nigeria
12	TAYLOR AND FRANCIS	Journal of the Air & Waste Management Association	Mmereki et al. (2015)	Waste electrical and electronic equipment management in Botswana: Prospects and challenges	Botswana
13	TAYLOR AND FRANCIS	Toxicological & Environmental Chemistry	Nnorom and Osibanjo (2011)	Determination of metals in printed wiring boards of waste mobile phones	Nigeria
14	SAGE	Environment and Planning C: Government and Policy	Lawhon (2013)	Dumping Ground or Country-in-Transition? Discourses of E-Waste in South Africa	South Africa
15	SAGE	The Journal of Environment & Development	Oteng-Ababio et al. (2020)	Building Policy Coherence for Sound Waste Electrical and Electronic Equipment Management in a Developing Country	Ghana
16	SAGE	Science, Technology and Society	Bob et al. (2017)	Enhancing Innovation and Technological Capabilities in the Management of E-Waste: Case Study of South African Government Sector	South Africa
17	SAGE	Global Health Promotion	Yu et al. (2017)	Informal processing of electronic waste at Agbogbloshie, Ghana: workers' knowledge about associated health hazards and alternative livelihoods	Ghana
18	SAGE	Proceedings of the Human Factors and Ergonomics Society Annual Meeting	Acquah et al. (2019)	Processes and challenges associated with informal electronic waste recycling at Agbogbloshie, a suburb of Accra, Ghana	Ghana

(Continued)

<i>(Continued)</i>					
No.	Database	Journal	Author/(s)	Title of Paper	Country
19	SAGE	Global Health Promotion	Tetteh and Lengel (2017)	The urgent need for health impact assessment: proposing a transdisciplinary approach to the e-waste crisis in sub-Saharan Africa	Africa in general
20	SAGE	Waste Management & Research	Ghosh et al. (2016)	Waste electrical and electronic equipment management and Basel Convention compliance in Brazil, Russia, India, China and South Africa (BRICS) nations	Africa in general
21	SPRINGER	Journal of Occupational Medicine and Toxicology	Burns et al. (2019)	Stress, health, noise exposures, and injuries among electronic waste recycling workers in Ghana	Ghana
22	SPRINGER	Modeling Earth Systems and Environment	Peluola (2016)	Investigation of the implementation and effectiveness of electronic waste management in Nigeria	Nigeria
23	SPRINGER	Environmental Science and Pollution Research	Isimekhai et al. (2017)	Heavy metals distribution and risk assessment in soil from an informal E-waste recycling site in Lagos State, Nigeria	Nigeria
24	SCIENCE DIRECT	Heliyon	Adanu et al. (2020)	Challenges of adopting sustainable technologies in e-waste management at Agbogbloshie, Ghana	Ghana
25	SCIENCE DIRECT	Journal of Radiation Research and Applied Sciences	Jibiri et al. (2014)	Assessment of radiation exposure levels at Alaba e-waste dumpsite in comparison with municipal waste dumpsites in southwest Nigeria	Nigeria



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