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(Review Article)

# E-waste landscape on the environment and human health: A bibliometric analysis

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## Abstract

Electronic waste (e-waste) has become relevant to the impact on the environment and human health. The mass production of equipment and devices makes them more affordable for consumers and promotes, in exchange, a short time of use and disposal growth. In this regard, the present work conducted a literature mini-review based on bibliometric analysis, using the SCOPUS database to obtain records of research articles from 2019 up to date. The purpose is to grasp an overview of the impact of e-waste on the environment and health. Therefore, the study revealed works that addressed such topics and identified the journals with the most articles published in this period. Moreover, the analysis exhibits the research collaboration among authors, countries, and highly cited authors, highlighting the contribution of developing countries such as Mexico, Brazil, Thailand, Nigeria, Indonesia, and Vietnam and exposing the current trends and future directions to mitigate this worldwide concern. The reviewed works emphasized the relevance of employing sustainable methods and supporting the circular economy at the disposal of e-waste. They also highlighted the need for creating and implementing policy and regulation frameworks, especially in developing countries, in parallel with encouraging corporate and consumer responsibility in e-waste management to raise awareness about eco-friendly practices and promote a greener and healthier future.

**Keywords:** E-waste; Human Health; Environment; Bibliometric Analysis; Pollution

## 1. Introduction

The rapid adoption of electronic devices (e.g., computers and mobile phones) has enhanced living standards but raised concerns about electronic waste (e-waste) due to environmental and health challenges [1]. Annually, millions of these devices are discarded as they break or become obsolete, contributing to global e-waste. It is growing five times faster than recycling, with a record 62 million tonnes produced in 2022 [2]. Additionally, when e-waste is recycled using rudimentary methods, it can release up to 1000 different chemical substances into the environment, posing health and environmental risks [3]. Unfortunately, e-waste is often recycled using unsound activities, releasing toxic substances, including heavy metals like lead (Pb) and mercury, and organic pollutants such as brominated retardants [4]. Moreover, operators involved in the e-waste recycling task face direct exposure to these chemicals through inhalation, ingestion, or skin absorption [5], likely causing health complications in these workers later on. Not to mention that the poor handling of e-waste also negatively affects the environment. E-waste has become a worldwide concern and drives to implement policies for proper management and disposal, especially in developing countries aiming to achieve sustainable development goals [6].

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E-waste can be categorized into ten main categories, including large and small home appliances (e.g., refrigerators), IT and communications equipment (e.g., computers), and non-infected medical devices (e.g., X-ray machines). Each has several building blocks, which are also classified, such as metals, plastics, insulation, wires, and circuit boards [7]. E-waste management remains inefficient due to poorly defined procedures, leading to improper recycling and disposal. It is mainly driven by the lack of legislation for effective recovery mechanisms and ignorance about the toxic hazards of e-waste [8]. For instance, the recycling rate of e-waste varies significantly across European countries, with considerable disparities observed among member states [9]. That means humans, organisms, and the environment are exposed to harmful chemicals through e-waste. Health risks vary based on the chemicals and recycling methods, with combined exposures potentially worsening the effects [10]. It is worth mentioning that even well-known technologies such as the pyrolysis process that is in line with circular economy require ecotoxicity testing and a volatile organic compounds analysis to evaluate potential risks from toxic substance release (e.g., the char obtained from a flat panel display cannot be used in soil due to its high content of dangerous elements, exceeding legal limits) [11].

This work aims to deliver a perspective on the implications of e-waste in the environment and human health. The study conducted a bibliometric analysis to identify the most recent relevant topics about e-waste's environmental and health impact. In this sense, a literature mini-review was undertaken to gain insights into e-waste topics. The purpose is to raise awareness about sustainable practices, provide actionable insights for proper e-waste management, and mitigate this worldwide concern.

## 2. Material and methods

This study employed bibliometric analysis as a quantitative method to explore scientific literature using the Vosviewer tool [12]. The data recovered were analyzed with such software to visualize output maps, which represent networks of the data and information, including authors, keywords, countries, and documents. For instance, it allows visualizing documents as nodes in a 2D space, connected by citation-based edges. VOSviewer groups nodes into clusters of closely related publications and creates a representation of citation patterns [13]. The bibliometric analysis delivers a network map that shows predominant authors' clusters. In addition, the analysis reveals collaboration among countries and the co-occurrence of author keywords. The bibliometric analysis exhibits the 15 most cited articles. Hence, the full documents were recovered to obtain information and describe e-waste management efforts for the environment and human health. The literature review was conducted using the SCOPUS database as a primary source of information. The database search was executed on January 7, 2025, and retrieved 535 records. The search string employed filters to include only documents of article type at the final publication stage. The period considered is from 2019 to 2025 and is limited to articles written in the English language, as follows:

*TITLE-ABS-KEY ( ( "electrical waste" OR "electronic waste" OR e-waste OR weee ) AND ( "human health" OR ( health AND environment ) ) ) AND PUBYEAR > 2018 AND PUBYEAR < 2026 AND ( LIMIT-TO ( PUBSTAGE , "final" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) )*

A screening process was performed on the retrieved records to search for the word *review* in the title of each article. The articles that contained such a word, 26, were removed. After conducting the VOSviewer analysis for the most cited documents, nine articles of review type were found and removed. As a result, 500 records were considered in the study. The distribution of published articles by year is 70 in 2019, 78 in 2020, 67 in 2021, 85 in 2022, 97 in 2023, 92 in 2024, and 11 in January 2025. Except for 2025, which is still in progress, 2021 contains the lowest number of published articles –it might be due to the COVID-19 outbreak. Figure 1 depicts the journals with the most published articles in the search range, accounting for 30 in 2019, 37 in 2020, 26 in 2021, 37 in 2022, 35 in 2023, 26 in 2024, and 5 at the beginning of 2025. The three journals with the highest number of published articles were *Science of the Total Environment* with 45 articles (22.9 %), *Environmental Pollution* with 20 articles (10.2 %), and *Environmental Science and Pollution Research* with 19 articles (9.7 %), representing 42.8 % of the total number of articles published.

## 3. Results and discussion

Figure 2 shows co-authorship analysis by authors. Each node represents an author, and the closest nodes form a cluster. The node size is associated with the number of documents where the author appears, and its color is related to the document publication year. Figure 2a depicts the most significant 300 of more than 2000 authors with at least one document and the highest total link strength, releasing 59 clusters. It can be seen as a collaboration among authors who worked on at least one article. The main clusters have 48 items (center, author Haryanto, Budi – 2 documents), 21 items (lower right, author Wei, Yongjie – 7 documents), 14 items (lower left, author Sun, Howgwen - 6 documents), 13 items (upper center, author Hasan, Shaikh Sharif – 4 documents) and 13 items (center right, Liu, Xingmei – 7 documents).

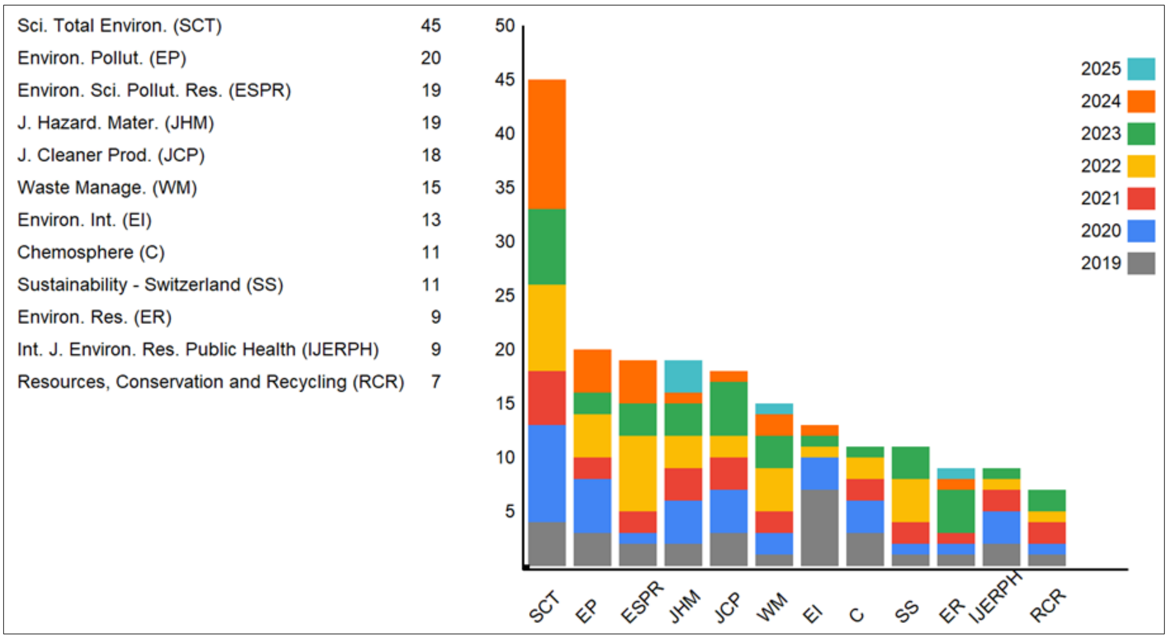


**Figure 1** Journals with the highest frequencies of the records retrieved

Figure 2b illustrates co-authorship analysis with at least two documents, limiting the results to 218 authors that form 50 clusters. It is worth mentioning that from the clusters in Figure 2a remain those with two or more documents, and the authors by cluster under these conditions were reduced. In compliance with the conditions, increasing the number of documents implies reducing the number and size of clusters, eventually disappearing the clusters. For instance, from the largest cluster in Figure 2a, the author Haryanto stays as a single member of the cluster and appears isolated (lower left). Although, if the number of documents increases to three, such an author would disappear. Figure 2b displays the predominant clusters: one contains 13 items (center, author Aich, Nirupan – 4 documents), one with 12 items (lower left, author Jones, Kevin – 3 documents), and three with 11 items (upper right, author Wei Yongjie; lower right, author Liu, Xingmei; and upper center, Li, Guiying - 5 documents). The cluster containing the author Wei Yongjie, delimited by a blue line, has a link with a cluster of 7 items (Wong, Ming Hung - 5 documents) delimited by a yellow line. The behavior of the clusters when increasing the number of documents reveals nourished research groups of authors working on e-waste topics with a high production of articles from 2019 to 2025.

Figure 3 exhibits the network map collaboration by countries, where the node size represents the number of documents, the links mean the participation between countries, and the thickness of the link reflects the frequency of collaboration. There are six clusters displayed, and three contain eight countries: one appears in red formed by Canada, Egypt, India, Iran, Malaysia, Pakistan, Saudi Arabia, and Turkey; another in green includes Brazil, France, Greece, Italy, Mexico, Portugal, Spain, and the United Kingdom; and the last cluster in blue by Indonesia, Japan, South Korea, Switzerland, Taiwan, Thailand, United States and Viet Nam. The network map reveals that China has a predominant collaboration, the strongest one with the United States, followed by Hong Kong and the Netherlands. Likewise, India, Canada, the United Kingdom, and Australia keep stronger research collaborations with China. Moreover, developing countries such as Mexico, Brazil, Thailand, Nigeria, Indonesia, and Viet Nam also contribute to e-waste research. For instance, Nigeria has a strong partnership with the United Kingdom, Vietnam with Japan, and Thailand with the United States. To a lesser extent, Brazil with the United Kingdom and Mexico with Canada.

Figure 4 displays a network map of co-occurrence by author keywords with a minimum number of five occurrences. Similar keywords such as *waste electrical and electronic equipment*, *weee*, and *electronic waste* were replaced by *e-waste*; whereas *polybrominated diphenyl ethers*, *PBDEs*, and *brominated flame retardants* were replaced by *flame retardants*. There are 41 keywords grouped in seven clusters, where the node size represents the number of occurrences among documents. For instance, e-waste, included in a purple cluster of five keywords, presents 200 occurrences and 42 links. The strongest links from largest to smallest connect with *heavy metal*, *recycling*, *health risk assessment*, and *sustainable development*. Moreover, the largest cluster is the red one formed by 11 keywords (e.g., *health risk assessment* with 49 occurrences), followed by a green cluster of eight keywords (e.g., *recycling* with 38 occurrences), a blue cluster of six keywords (e.g., *Pb* with 13 occurrences), and a yellow cluster of five keywords (e.g., *sustainable development* with 27 occurrences). In addition, some countries reveal some topics of interest, such as China and Ghana, which are related to informal recycling that produces air and soil pollution with human health concerns.

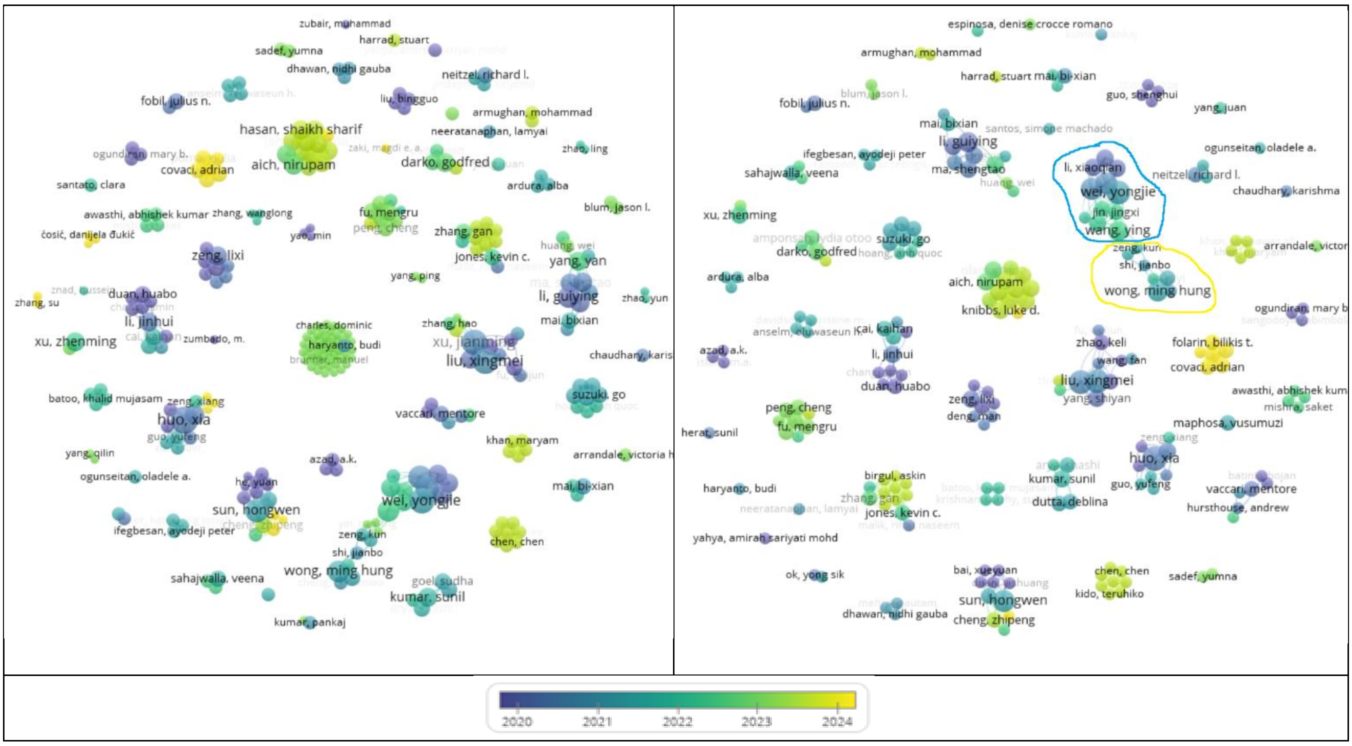


**Figure 2** Network visualization map by authors and document year publication: (a) Restricted to at least one document, (b) Restricted to at least two documents

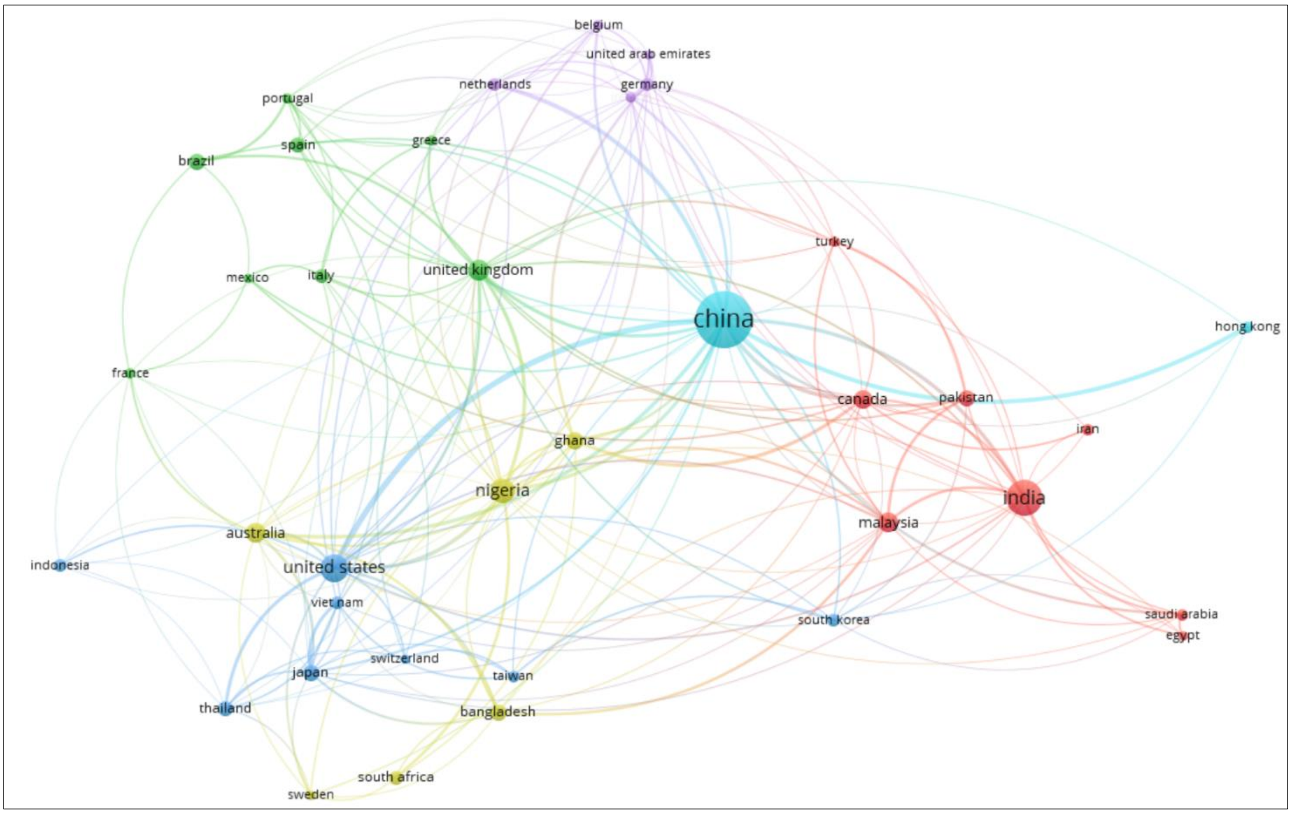


**Figure 3** Country collaboration, six clusters by color - 37 of the 83 countries have at least five publications

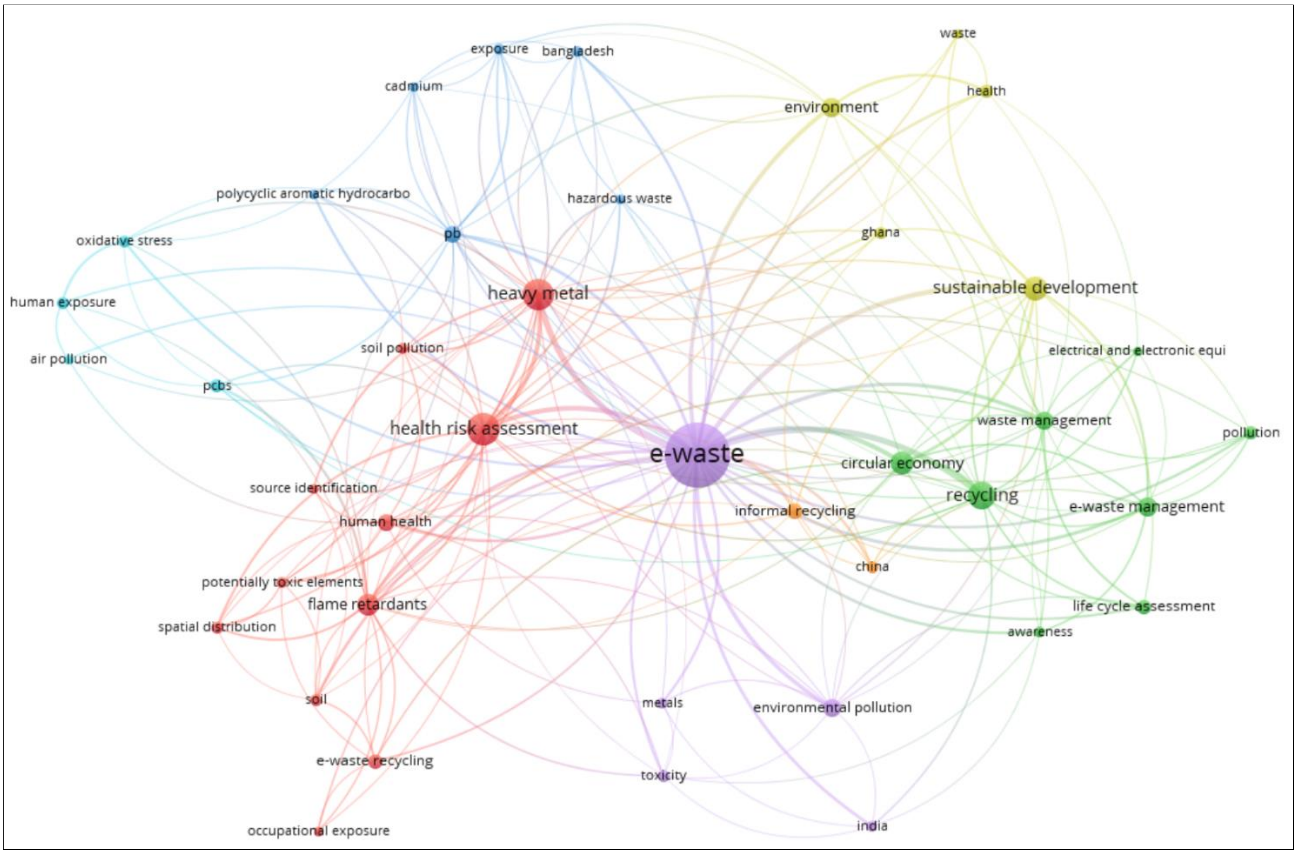


**Figure 4** Network map of co-occurrence by author keyword restricted to five occurrences

The selection of the 15 most cited articles includes at least 91 citations for each one. Table 1 presents the authors, citations, digital object identifier, and the number of citations. Liu et al. (2020) explored the feasibility of recycling hazardous Pb e-waste. They employed ultrahigh-performance concrete, revealing that its microstructure and low permeability are a safe and effective way to recycle e-waste without concerns about Pb contamination. Zhao et al. (2020) presented a method for recycling lithium from spent batteries using microwave pyrolysis of macadamia nut shells, achieving a 93.4% recovery rate. Further, Ulla and Sarkar (2020) proposed a dual-recovery-channel hybrid model based on a mathematical model for an optimal collection strategy to increase the very low recycling rate in the cell phone supply chain. Garg (2021) developed a combined framework using the Grey concept and DEMATEL technique to analyze the interdependencies of e-waste mitigation strategies. They offered valuable insights for policymakers and managers addressing e-waste in India.

Since heavy metals are a worldwide concern, Budnik and Casteleyn (2019) focused on mercury tain and its socio-medical consequences. They propose preventive measures and human biomonitoring programs about contaminant exposures for decision-making. Zhang et al. (2019) assessed Pb contamination in surface soils across China, focusing on pollution levels, sources, and health risks. They emphasized the need for comprehensive monitoring, pollution control, site management, and sustainable remediation. In addition, Khan et al. (2020) examined the effect of amending Pb-contaminated soil from Pb-acid battery recycling, which poses health risks via food. They studied lignin-derived biochar plus arbuscular mycorrhizal fungi for remediating Pb-polluted soil and producing safer cereals. Jiang et al. (2019) analyzed the impact of heavy metal e-waste contamination in Nigeria on soil microbial communities, where the distribution of metals was related to metal mobility and speciation. Thus, the bacterial taxonomic composition in the polluted and unpolluted zones varied significantly. Zhao et al. (2019) examined e-waste dismantling pollution, focusing on hazardous metals in paddy soils and groundwater and finding their concentration in the topsoil and shallow groundwater. Furthermore, it is urgent to adopt sustainable green remediation methods to ensure food safety and protect human health, as pointed out by He et al. (2019), who evaluated heavy metal contamination in farmland soil and rice grains from a former e-waste dismantling region. They found heavy metal trails in the soil, and 20.7 % of rice samples exceeded the cadmium threshold. Yang et al. (2019) examined the sources, exposure, and health risks caused by heavy metals in soil in an e-waste dismantling site. Based on a model found that industrial discharge contributes the most to cancer risk (45.3%) despite its slight role in metal accumulation.

**Table 1** Fifteen most cited articles

| Top | Citation | Digital Object Identifier | # of Citations |
|---|---|---|---|
| 1 | Jiang et al. (2019) | 10.1016/j.jhazmat.2018.08.060 | 276 |
| 2 | Budnik and Castelyn (2019) | 10.1016/j.scitotenv.2018.10.408 | 215 |
| 3 | Ullah and Sarkar (2020) | 10.1016/j.ijpe.2019.07.017 | 158 |
| 4 | Yang et al. (2019) | 10.1016/j.envint.2019.105239 | 158 |
| 5 | Gangwar et al. (2019) | 10.1016/j.envint.2018.11.051 | 138 |
| 6 | Khan et al. (2020) | 10.1016/j.scitotenv.2019.136294 | 129 |
| 7 | Zhang et al. (2019) | 10.1080/10643389.2019.1571354 | 127 |
| 8 | Liu et al. (2020) | 10.1016/j.jclepro.2019.119333 | 122 |
| 9 | He et al. (2019) | 10.1016/j.envpol.2018.10.070 | 119 |
| 10 | Garg (2021) | 10.1016/j.jclepro.2020.124035 | 113 |
| 11 | Landrigan et al. (2023) | 10.5334/aogh.4056 | 110 |
| 12 | Ge et al. (2020) | 10.1016/j.envint.2020.105741 | 105 |
| 13 | Zhao et al. (2020) | 10.1016/j.jhazmat.2020.122740 | 96 |
| 14 | Liu et al. (2021) | 10.1016/j.scitotenv.2021.146438 | 95 |
| 15 | Zhao et al. (2019) | 10.1016/j.geoderma.2018.10.004 | 91 |

Liu et al. (2021) investigated farmland quality around an e-waste dismantling site, focusing on heavy metal contamination in vegetables and its health risks. Health risk assessments indicated potential non-carcinogenic and carcinogenic risks for both adults and children, with lettuce and sweet potatoes posing the highest risks. Gangwar et al. (2019) analyzed the environmental and health risks of an illegal e-waste recycling site by monitoring air pollution of PM10 and heavy metals. The results showed that exposure to high levels leads to a higher prevalence of hypertension among residents. Landrigan et al. (2023) examined plastics' impacts across their life cycle on human health, the environment, the economy, and vulnerable populations. Their production, use, and disposal are unsustainable, and plastic-laden e-waste is particularly problematic. Ge et al. (2020) studied the effects of flame retardant emissions from e-waste dismantling on surrounding areas and human health. They found higher soil contamination levels where individuals were not exposed to non-carcinogenic health risks, though the total risk from multiple contaminations should be considered.

In summary, the reviewed works highlight the risks and consequences to the environment and health emanating from inadequate e-waste disposal and the content of chemical substances and environmental toxicants. For instance, Budnik and Casteleyn (2019) remark that mercury pollution exposures and health effects require a swift translation into adequate preventive actions. Moreover, when lead, other heavy metals, and brominated flame retardants are managed poorly by informal scrappers, individuals can be directly exposed to these chemicals through inhalation, ingestion, or skin absorption [5,7]. On the other hand, e-waste landfills and dismantling sites are also urgent concerns, in many cases, given their proximity to bodies of water and soil for growing food [22, 25]. Therefore, sustainable and green remediation methods to guarantee food safety [23], actionable measures, and strategies are essential to reduce pollution from heavy metals and mitigate health risks. In addition, bibliometric analysis stresses relationships between authors, countries, and keywords. China and the United States are distinguished by their stronger collaboration, whereas developing countries have been exhibiting considerable participation in environmental and human health concerns about e-waste management strategies. For instance, Nigeria presents a synergy with 21 countries and 33 articles, and India with 17 countries and 72 articles.

The present research has several primary limitations. First, the study is limited to using the SCOPUS database as a unique source. Another constraint is the application of specific search filters, such as document type, date range, and language, which further reduces the number of records available for analysis. Also, it relies on a selective small sample of the 15 highly cited articles obtained from the bibliometric analysis with VOSviewer for a comprehensive review.

## 4. Conclusion

The review study revealed a landscape of relevant e-waste topics that impact the environment and human health. It presents authors' collaboration, countries' connections with specific e-waste topics, the relevant keyword relationships, and describes the most cited articles. Overall, it exposes the importance of global concerns caused by the growing pace of e-waste in recent years and the pertinency of employing sustainable methods, technologies, and techniques to promote a circular economy in e-waste management. It is relevant to compensate for the damage caused by inadequate waste dumping. For instance, remediating Pb-polluted soil with arbuscular mycorrhizal fungi to produce safer cereals [20] and promote better ways to mitigate e-waste disposal by employing concrete as a safe and effective way to recycle Pb e-waste [14]. There is a worldwide collaboration among countries to face several e-waste challenges. In the analysis performed with the VOSviewer tool, China appeared as the leader in the number of published articles, showing the strongest collaboration links with countries such as the United States, Hong Kong, and the Netherlands.

It is worth noting that several developing countries are also concerned with the rising issues related to e-waste, especially those that receive used electrical and electronic equipment with a short life cycle from developed countries or those serving as countries for dumping to extract precious metals from the waste produced [29]. Future work includes executing a broader search in other well-known databases such as Web of Science, IEEE Xplore, and PubMed. It is also relevant to conduct a study among continents such as America, the European Union, and Africa to capture a snapshot of the status of the e-waste phenomenon. In this context, a study is encouraged to analyze the endeavors of research focused on standard measurements and metrics to quantify e-waste rates.

## Compliance with ethical standards

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### *Disclosure of conflict of interest*

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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