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Waste Management Research in Sri Lanka: Exploring Trends, Identifying Gaps, and Gaining Key Insights Through Bibliometric Analysis

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Abstract: Waste generation has emerged as a critical global challenge, driven by rapid urbanization, industrialization, and evolving consumption patterns with insatiable needs and a shift away from minimalization. In 2023, cities worldwide generated 2.3 billion tonnes of solid waste annually, whereas Sri Lanka accounts for millions of tonnes annually. Continued waste generation is expected to increase from 2.3 billion to 3.8 billion tonnes by 2050. Despite the global emphasis on advanced waste management practices such as recycling, composting, and circular economy models, there is a notable lack of systematic understanding of the research landscape in developing nations like Sri Lanka. This absence creates a critical gap in identifying the evolution, key contributors, and dominant themes in the country's waste management area. To bridge this gap, bibliometric analyses offer a structured way to explore trends and identify key contributors in the field. This study aims to present a comprehensive bibliometric review of waste management research conducted in Sri Lanka, providing insights into its evolution, dominant themes, and emerging research directions. Using 235 research articles published between 1990 and 2023 and data extracted from the OpenAlex database, the analysis was conducted with Biblioshiny software to examine publication trends, collaboration networks, and thematic evolution. Key findings are summarized into five main points. First, research output has steadily increased since 2010, with a remarkable growth peak around 2020, reflecting growing scholarly interest. Second, the University of Moratuwa emerges as a dominant contributor, alongside international collaborations with institutions from countries like the United States, Australia, and the United Kingdom. Third, thematic analysis reveals that sustainability practices, waste-to-energy conversion, and recycling are dominant themes. At the same time, policy development, public participation, and electronic waste management are identified as emerging research areas. Fourth, bibliometric data emphasizes the role of influential journals like Waste Management and Journal of Material Cycles and Waste Management in shaping the field. Finally, keyword analysis highlights interconnected themes such as environmental monitoring, public health concerns, and the socio-economic aspects of waste management. This bibliometric review, focused on Sri Lanka, provides a foundation for scholars, policymakers, and practitioners to identify critical gaps and advocate for the integration of innovative technologies and cross-disciplinary strategies that advance sustainable waste management practices and policy development.

Keywords: waste management; exploratory research; bibilometrics analysis; sustainability practices; waste-to-energy conversion; recycling.

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Introduction

Waste disposal generates both direct and indirect environmental impacts, including land occupation, resource depletion, and the intensification of global warming through the release of methane and other greenhouse gases, water contamination due to landfilling, and the acidification and toxic effects of air emissions from incineration (Fadel, Findikakis, & Leckie, 1997). While the direct impacts of waste contribute significantly to climate change, they constitute a relatively small portion of the overall effects. Resource depletion and related impacts are primarily linked to indirect environmental consequences, which stem from the extraction and processing of resources needed to produce various products (He, Wang, & Chen, 2024). Consequently, the indirect effects of poor waste management can be more severe and have a greater potential impact than the direct effects (Towa, Zeller, & Achten, 2020).

The domestic definition of waste in Sri Lanka is outlined in national legislation and policy. According to the National Environmental Act (Act No. 47 of 1980), "Waste includes any matter prescribed to be waste and any matter, whether liquid, solid, gaseous, or radioactive, which is discharged, emitted, or deposited in the environment in such volume, constituency or manner as to cause an alteration of the environment." The National Policy on Waste Management (2020) further defines waste as "any material, substance or by-product eliminated or discarded or as no longer required at a particular time and a particular place or form and therefore to be used either as a resource or to be treated and disposed of in an environmentally sound manner if it does not have a utility value." These definitions highlight the broad scope of waste and the need for effective waste management strategies where law alone can not make a change.

Waste management is an activity that involves all the techniques and processes adopted in sorting, controlling, and treating different types of waste from the source of generation to the point of final disposal (Tanveer et al., 2022). Waste prevention, reusing, and recycling whenever possible to reduce environmental impacts are considered effective means of implementing waste management (Das et al., 2019). This is especially remarkable from a life-cycle perspective, considering both the direct and indirect effects, such as emissions and resource depletion. Methods of disposal such as landfilling and incineration cannot be considered as best practices for material resources efficiency of separately collected recyclables and mixed Municipal Solid Waste (Assamoi & Lawryshyn, 2012). It is important to measure the environmental, economic, and societal impacts of such disposal methods to understand the benefits of adopting proper waste management practices (Torkayesh et al., 2022).

Several government and international organizations play major roles in regulating and managing the waste management sector in various aspects. Examples include municipalities and environmental governmental agencies that coordinate to formulate legislation and benchmarks for facility waste management while overseeing municipal waste management and hazardous waste treatment operations (Nilsson, Eklund, & Tyskeng, 2009). The U.S. Green Building Council has set standards regarding construction waste management and facility daily operations through its Leadership in Energy and Environmental Design, or LEED (Wu, Mao, Wang, Song, & Wang, 2016). Meanwhile, the International Standards Organization and the European Union also help frame standards for, in this case, waste management, among many other fields represented by ISO 14001 and EMAS, respectively (Testa et al., 2014). Typical goals and drivers for these organizations include resource efficiency, waste reduction, cost minimization, enhancement of competitive edge through supply chains, compliance with the law, customer confidence, and consistency in the management of environmental performance (Bastas & Liyanage, 2019). Together, these elements form the foundation of effective waste management approaches.

Most developing and least developed nations struggle with domestic and transboundary waste management approaches. In 2012, cities worldwide produced 1.3 billion tons of solid trash annually, or 1.2 kg per person per day. This number is forecasted to increase up to 2.2 billion tons (MT) by 2025 due to increasing urbanization and population development with insatiable needs (The World Bank, 2012). Inevitably, if current trends continue, it is expected to increase from 3.5 MTs to 6 MTs per day, with each individual in Sri Lanka producing around 0.64 kg of waste per day and the country collecting an estimated 4.8 billion MT of waste annually (Dharmasiri, 2019). The lack of adequate systems for collection, transportation, and disposal has made waste management a major problem in Sri Lanka (Vidanaarachchi, Yuen, & Pilapitiya, 2006). Although households produce the majority of waste, industries are also integral to the issue. The problem is less life-threatening in suburban and rural locations because there is more space available for disposing of junk (Fernando, 2019). However, managing waste poses a significant challenge in urban areas, especially in the Western Province (Kumara & Pallegedara, 2020).

As of March 2021, Sri Lanka generated about 9,811 metric tons per day of municipal solid waste, of which 3,767 tons were collected. That means only half of the produced amount is collected (EFL, 2017). The contribution of the Western Province alone accounts for almost 60% of the waste generation, and the average quantity of 1–0.4 kg of waste generated per person per day. According to the Local Government Act, Sri Lankan Local Authorities are responsible for collecting and disposing of waste generated by residents under their jurisdiction. The required provisions are found in sections 129, 130, and 131 of the Municipal Council Ordinance, sections 118, 119, and 120 of the Urban Council Ordinance, and sections 93 and 94 of the Pradeshiya Sabha Act (Shukri & Jayasena, 2024). National Solid Waste Management Strategy (NSSWM), issued by the Ministry of Forestry and Environment in 2002, emphasizes the importance of integrated solid waste management and gives broad advice for handling solid waste in the country. Municipal solid waste management entails more than just waste collection; it encompasses a variety of tasks that must be carried out together with residents. These actions include developing guidelines for effective waste management, creating community awareness, and providing essential infrastructure. In Sri Lanka, such initiatives are frequently hampered by limited resources, resulting in ineffective implementation in local government institutions (Fernando, 2019).

Several empirical studies have investigated waste management in Sri Lanka, revealing a variety of challenges and breakthroughs. Zhao, Diunugala, and Mombeuil (2021) used Structural Equation Modelling (SEM) on a sample of 335 households in Colombo, finding that family size and household income had a positive influence on weekly waste generation, whereas the household head's knowledge and awareness of waste management had a negative impact. Aslam, Zimar, and Junaideen (2021) used a mixed-methods approach to analyze qualitative data from 24 key informants in the Kalmunai municipal council, concluding that municipal solid waste management was ineffective due to inadequate waste segregation at the source, insufficient resources, and a lack of regulations to control polluters. Multinomial Logistic Regression Analysis was used by (Kumara & Pallegedara, 2020) to analyze data from 60,820 households in Sri Lanka's Household Income and Expenditure Survey (2007-2016). The results demonstrated a significant impact of socioeconomic characteristics on waste disposal methods and increased demand for local government waste collection services. Fernando (2019) found that compensation, staff commitment, political leadership, and business and societal support are critical elements for the successful implementation of solid waste management programs. He conducted this analysis with 125 administrative heads, officers, and public health officials in the Western Province. These studies highlight the need for better policies and strategies by offering insightful information about the difficulties and efficacy of waste management systems in Sri Lanka. Due to the importance of the construct, several review studies on waste management in Sri Lanka

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have been conducted in the past. However, these studies differ significantly from the current review (See Table 1).

Table 1. Summary of existing reviews on waste management in Sri Lanka

Source of the review	Insights
(Kularatne, 2023)	The review identifies significant issues with hazardous waste management in Sri Lankan EA laboratories. Despite low effluent volumes, there is high pollution due to contamination. Laboratories produce 80–100 kg/year of chemical-contaminated waste, with inadequate disposal methods—ranging from mixing with non-hazardous waste to dumping and burning, though one lab uses co-processing.
	Current management practices and regulations are insufficient, underscoring the need for improved waste management strategies and cleaner production practices.
(Welivita , Wattage, & Gunawardena, 2015)	The study investigates difficulties with solid waste management (SWM) in developing nations, emphasising household solid waste (HSW). It emphasizes the significance of the "4R" activities: reducing, reusing, recycling, and recovering in minimizing waste.
	The Waste Management Charge (WMC) is seen as a successful instrument for encouraging these habits. After assessing several charging methods, the report proposes a 'pre-paid bag-based charging system' as the best fit for Sri Lanka, taking into account social, economic, and political issues. The findings recommend implementing Quantity-Based Charging (QBC) systems in similar developing countries.
(Weerasundara, 2014)	This article examines waste management techniques, legislative and institutional frameworks, and technologies employed in Sri Lanka to determine the scope of non-hazardous and hazardous waste issues.
	The study, which is based on a literature analysis, has concluded that while Sri Lanka has a well-developed legislative and institutional framework with established laws and norms, novel technologies are required to improve existing waste management practices.
	The study also cites considerable opportunities for private-sector involvement in garbage management. It finds that a thorough technical assessment and the development of new technologies are required to adequately manage all forms of garbage in the country.
(Widanapathirana, Perera, & Bellanthudawa, 2023)	This study explores e-waste management in Sri Lanka, noting important issues such as ineffective policies, insufficient recycling procedures, and a lack of knowledge. It identifies the necessity for strategic planning in the technological, financial, and institutional domains.
	Key ideas include adopting e-waste legislation, establishing central management bodies, assisting informal recyclers, and incorporating e-waste management into education to enhance practices and understanding.
(Nayanarangani, Dissanayaka, & Jaya, 2022)	The study has explored that tourism considerably enhances Sri Lanka's economy, accounting for 12.6% of GDP, but also produces a huge amount of solid garbage. Depending on tourist behaviour, seasons, and local legislation, tourist destinations generate between 1 and 12 kg of waste per guest per day.
	Key issues include insufficient facilities, bad administration, and financial limits. The report underlines the importance of improving waste management for Sri Lanka's long-term tourism and economic growth.

Source: own processing

Prior bibliometric analyses have examined a range of waste management topics, such as household waste generation (Zhao, Diunugala, & Mombeuil, 2021), municipal solid waste management (Aslam, Zimar, & Junaideen, 2021), waste disposal behaviour (Kumara & Pallegedara, 2020) and solid waste management programs (Fernando, 2019). However, there is a notable absence of thorough studies concentrating specifically on waste

management research conducted in Sri Lanka. By conducting a thorough bibliometric analysis of waste management research conducted in Sri Lanka, our study fills this knowledge gap and provides fresh perspectives on this underrepresented field.

The identified shortfalls present research and development opportunities with substantial potential for growth in Sri Lanka's waste management sector. The current study, which utilizes a bibliometric analysis approach, serves as an important step forward in the field. The outcomes of this study will help to improve comprehension of the literature on waste management in Sri Lanka and contribute to the advancement of environmental sustainability practices in the region. As a result, this study covers the following eight research questions (RQs) through a detailed analysis:

RQ1. What are the descriptive characteristics of the refined empirical research on waste management in Sri Lanka?

RQ2. What are the trends in annual scientific publications and the thematic evolution of waste management research in Sri Lanka?

RQ3. Which sources are the most relevant and high-impact in waste management research in Sri Lanka?

RQ4. What are the globally most-cited articles on waste management in Sri Lanka?

RQ5. Who are the most relevant and high-impact authors in waste management research in Sri Lanka?

RQ6. Which countries are the most relevant in contributing to waste management research in Sri Lanka?

RQ7. What are the trending research areas and avenues for future research in the field of waste management in Sri Lanka?

The remaining sections of this research are arranged as follows: The research methodology used is described in depth in the next section. The bibliometric search results and the data's descriptive statistics are shown, and the data are formally analyzed in the latter section. The final section concludes by summarizing the results and outlining suggestions for additional studies on waste management in Sri Lanka.

Research methodology

Bibliometric analysis is a quantitative method used to evaluate and describe published research, focusing on the correlation and connections among articles. This approach systematically reviews past publications to identify trends and patterns, offering a reliable and replicable process that minimizes errors associated with manual and qualitative analysis, especially for large datasets. It aids in establishing research objectives, assessing research coverage, and identifying anomalies for further exploration. In this study, we employ a bibliometric methodology to comprehensively describe publication trends, influential authors, key journals, and significant papers in the field of waste management research in Sri Lanka. We will conduct citation, collaboration, and keyword analysis using the Biblioshiny function of the Bibliometrix package in R-studio for text mining. Additionally, we analyze co-occurrence conceptual structures and keyword selection to uncover main topics and emerging research frontiers. This bibliometric analysis provides a systematic and detailed view of the research landscape in waste management, facilitating a clearer understanding of complex data and supporting informed and strategic research decisions.

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Search results and data description

To find pertinent research articles on "Waste Management Research in Sri Lanka", we conducted a comprehensive search using the OpenAlex database, which, unlike Scopus and Web of Science, provides open access to a vast array of scientific literature (Simard, Basson, Hare, Lariviere, & Mongeon, 2024). We selected OpenAlex for its extensive and diversified collection of high-quality research publications. To ensure data integrity and minimize duplication, we only used OpenAlex articles in our research.

A search of the OpenAlex database for research articles, including the title and abstract "waste management" AND "Sri Lanka" from 1970 to 2024, produced a list of 475 published publications from over 214 sources. This thorough search allowed us to describe waste management in Sri Lanka articles in terms of time, as well as the top contributing institutions and countries, major contributing authors, and influential journals in this field. This method offers a complete view of the research environment, highlighting key trends and contributions to the study of waste management in Sri Lanka.

Data analysis

Descriptive features of the extracted data

Figure 1 shows a time series plot of the publication trend in waste management articles in Sri Lanka from 1990 to 2024. It can be seen that generally, the trend is increasing for the data, with several notable fluctuations during the period. From 1990 to 2000, there was a slow and continuous increase in the number of publications, while from 2000 to 2010, the pace quickened with a huge surge, indicating a growing interest in waste management research during this decade. From 2010 to 2015, the number of publications stayed about the same, but after 2015, there was a sharp rise, showing renewed research activity. The trend line equation, $y = 0.0603x^2 - 0.787x + 2.7029$, just suggests that this overall upward trend grows exponentially, especially in the second half of the period under study, denoting rapidly growing scholarly attention towards waste management in Sri Lanka. Although the data show an encouraging growth trend in interest in research, there are troughs and flattened periods, thus opening up potential gaps and periods with reduced interest in research. Further investigation into such periods may answer many problems related to waste management in Sri Lanka.

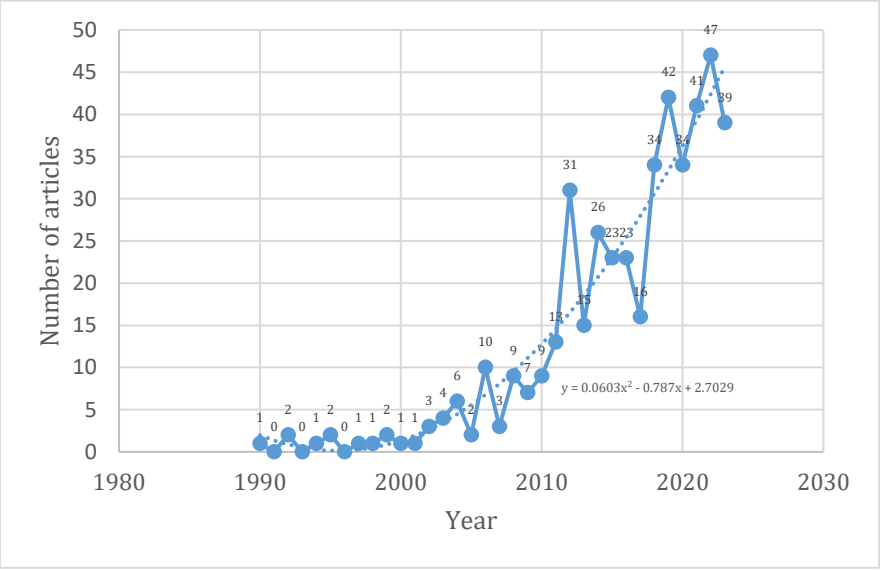

Figure 1. Annual production of articles
Source: own processing

The complete overview of research on waste management in Sri Lanka from 1990 to 2024, covering an analysis of 378 documents, including journals, books, and other publications, is presented in Table 2. The annual growth rate as a measure of research productivity is 3.42%, indicating growing interest in the area, but the average document age of 7.89 years shows some potential for more up-to-date research output. While it has an average of 31.77 citations per document, with a total of 4775 references cited, the research impact is thereby reasonable within the community. The collaboration is proved by an average of 2.85 co-authors per document. Articles are predominant in this data set, with an apparent focus on scholarly communication. The dataset is largely composed of articles emphasizing scholarly communication, though the absence of data on other document types like book chapters and conference proceedings limits a complete understanding of the research output. Keywords Plus and Author's Keywords provide a foundation for thematic analysis can be made, but more research is required conclusively to identify the core themes of research and their evolution over time. Additionally, the analysis reveals 1088 contributing authors, with 76 authors solely responsible for their publications, suggesting that a deeper examination of author productivity and collaboration could provide more insights into the structure of the research community.

Table 2. Summary of data

Description	Results
Timespan	2003:2024
Sources (Journals, Books, etc)	559
Documents	1247
Annual Growth Rate %	19.34
Document Average Age	5.35
Average citations per doc	28.5
References	20009
Keywords Plus (ID)	327
Author's Keywords (DE)	327
Authors	2794
Authors of single-authored docs	102
Single-authored docs	110
Co-Authors per Doc	4.03
International co-authorships %	0
article	1247

Source: output of Biblioshiny software

Top authors and journals

The current study examined 235 types of reliable sources. Figure 2 depicts the top ten sources of the highest number of scientific papers on waste management in Sri Lanka. Proceedings of International Forestry and Environment was placed first, with 18 documents. It was followed by the Journal of Material Cycles and Waste Management, which had eleven documents. Waste Management contributes the second biggest number of documents (10). Lecture Notes in Tropical Agricultural Research and Extension, Civil Engineering, the 11th World Construction Symposium, and the SSRN Electronic Journal each contributed six papers to the corpus. The Journal of Cleaner Production and the 10th World Construction Symposium both contain five publications.

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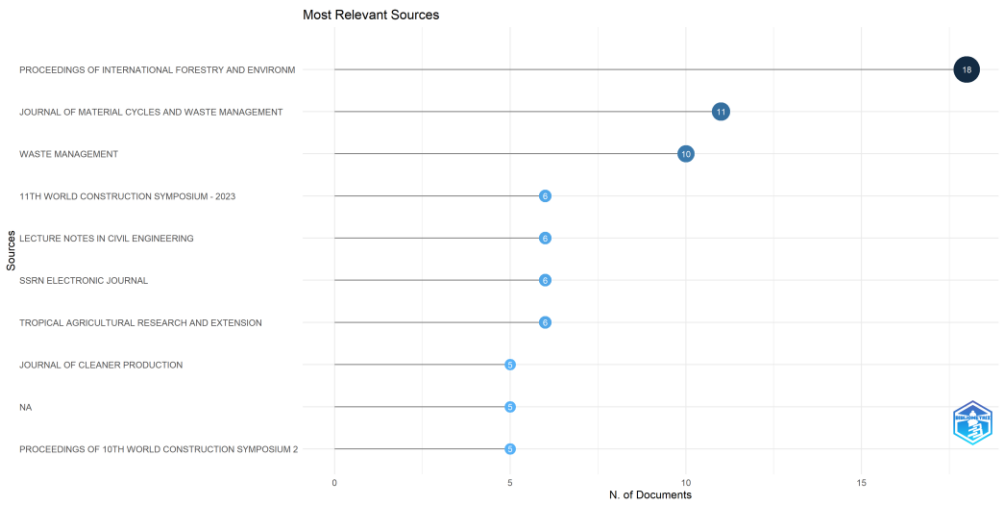

Figure 2. Top 10 journals
Source: own processing

Table 3 presents a significant study titled "Challenges of Waste Management in Developing Countries – A Case Study from Sri Lanka," authored by Nilanthi J. G. J. Bandara, J. Patrick A. Hettiaratchi, S. C. Wirasinghe, and Sumith Pilapiiya. Published in 2007 in the journal Environmental Monitoring and Assessment by Springer, this paper has had a lasting impact on the discourse surrounding waste management in developing nations. With 188 citations, it remains highly relevant more than a decade after its publication.

The study offers an in-depth analysis of the critical waste management challenges faced by Sri Lanka, providing a comprehensive evaluation of the environmental impacts and proposing practical improvement solutions. It is particularly notable for identifying significant gaps in existing waste management systems and emphasizing the importance of systematic monitoring and assessment to enhance regional sustainability. The enduring value of this paper is evident in its high citation count, reflecting its status as a foundational work for both researchers and policymakers focused on waste management.

Table 3. Top ten globally cited articles

Authors	Year	DOI	Source	TC
Nilanthi J. G. J. Bandara, J. Patrick A. Hettiaratchi, S. C. Wirasinghe, Pilapiiya, S.	2007	10.1007/S10661-007-9705-3	Environmental Monitoring And Assessment	188
Kularatne, T., Wilson, C., Månsson, J., Hoang, V., Lee, B.	2019	10.1016/J.TOURMAN.2018.09.009	Tourism Management	145
Aleluia, J., Ferrão, P.	2016	10.1016/J.WASMAN.2016.05.008	Waste Management	133
Morgan, O., Sribanditmongkol, P. Perera, W., Sulasmi, Y., Van Alphen, D., Sondorp, E.	2006	10.1371/JOURNAL.PMED.0030195	Plos Medicine	129
Dissanayake, D., Tilt, C., Xydias-Lobo, M.	2016	10.1016/J.JCLEPRO.2016.04.086	Journal Of Cleaner Production	126
Kulatunga, U., Amaratunga, D., Haigh, R., Rameezdeen, R.	2006	10.1108/14777830610639440	Management Of Environmental Quality	119
Vidanaarachchi, C. K., Samuel, T.,Yuen, S., Pilapitiya, S.	2005	10.1016/J.WASMAN.2005.09.013	Waste Management	112
Lalitha, R., Fernando, S.	2018	10.1016/J.WASMAN.2018.11.030	Waste Management	100
Abeyewickrema, W., Wickremasinghe, A. R., Sommerfeld, J., Kroeger, A.	2015	10.1179/2047773212Y.0000000060	Pathogens and Global Health	66
Menikpura, S. N. M., Shabbir, H. Gheewala, S.	2018	10.1007/S10163-012-0055-Z	Journal of Material Cycles and Waste Management	64

Source: output of Biblioshiny software

Among the 235 papers analyzed, Table 4 spotlights the most prolific authors in the field, emphasizing those with the most publications and their fractionalized contributions.

Table 4. The most prolific authors

Authors	Articles	Articles Fractionalized
Manfred Lenzen	45	9.78
Kuishuang Feng	41	7.91
Richard Wood	41	8.80
Bin Chen	36	9.05
Klaus Hubacek	31	5.77
Thomas Wiedmann	30	7.29
Dabo Guan	28	4.46
Sai Liang	24	3.91
Jing Meng	23	4.39
Daniel Moran	22	4.94

Source: output of Biblioshiny software

According to Table 5, Karunasena G stands out as the leading author, with nine articles and a fractionalized count of 3.75, underscoring their significant influence on the literature. Amaratunga D and Basnayake BFA follow closely, contributing 7 and 6 articles, respectively, with fractionalized counts of 2.67 and 1.78. These numbers not only highlight the volume of their work but also demonstrate their active participation and impact within their research areas. Karunasena G's prominent position underscores their crucial role in advancing the field, while the contributions from other authors such as De Alwis A, Ariyawansha Rtk, and Pilapitiya S also reflect their considerable influence on the ongoing academic discourse. The fractionalized article counts further emphasize the collaborative nature of research in this field, illustrating the extent of each author's involvement in multi-authored studies.

Table 5. Top ten most relevant authors

Authors	Articles	Articles Fractionalized
Karunasena G	9	3.75
Amaratunga D	7	2.67
Basnayake Bfa	6	1.78
De Alwis A	6	1.92
Ariyawansha Rtk	5	1.28
Pilapitiya S	5	1.42
Dissanayake P	4	1.50
Haigh R	4	1.17
Jayasinghe-Mudalige Uk	4	1.83
Karunarathna A	4	1.12

Source: output of Biblioshiny software

Collaborations

Figure 3 depicts worldwide collaboration on waste management research in Sri Lanka, highlighting the contributions of nations from Asia, North America, Europe, Africa, and Oceania. The most significant partnering nations, such as the United States, Australia, and the United Kingdom, have substantial research collaborations with Sri Lanka on waste management. The wider geographical distribution of the collaborations demonstrates that waste management in Sri Lanka is a worldwide concern since academics from all over the world participate. This represents an extraordinary international collaboration over the waste management problems in Sri Lanka and shows the integration of diverse views to handle those challenges. Participation by countries that represent different regions should imply that the research is enriched through a broad exchange of knowledge and expertise, hence increasing the overall impact and quality of the findings.

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Figure 3. Countries' collaboration world map
Source: output of Biblioshiny software

Most relevant affiliations

Affiliation analysis of waste management research in Sri Lanka shows that the University of Moratuwa is dominant, as it has taken a leading role in the field of studies in the Department of Building Economics with 18 publications. The major contributors, in order of precedence, were the Department of Information Technology, Sri Lanka Institute of Information Technology, with 10 publications; the Department of Civil Engineering of the University of Moratuwa, with nine publications; and the Department of Earth Resources Engineering, University of Moratuwa with eight publications. This was matched by the international perspective given by the Institute for Global Environmental Strategies with eight publications. It follows that there are seven publications from each university, reflecting regional interest: Sabaragamuwa University and Wayamba University. The Center for Supply Chain, Operations and Logistics Optimization at the University of Moratuwa and the Department of Agricultural Engineering at the University of Peradeniya have published each of 6 papers. This indicates a multi-disciplinary approach in waste management engineering, technology, environmental strategies, and logistics. The University of Moratuwa appears to be the hub among the four universities (Figure 4).

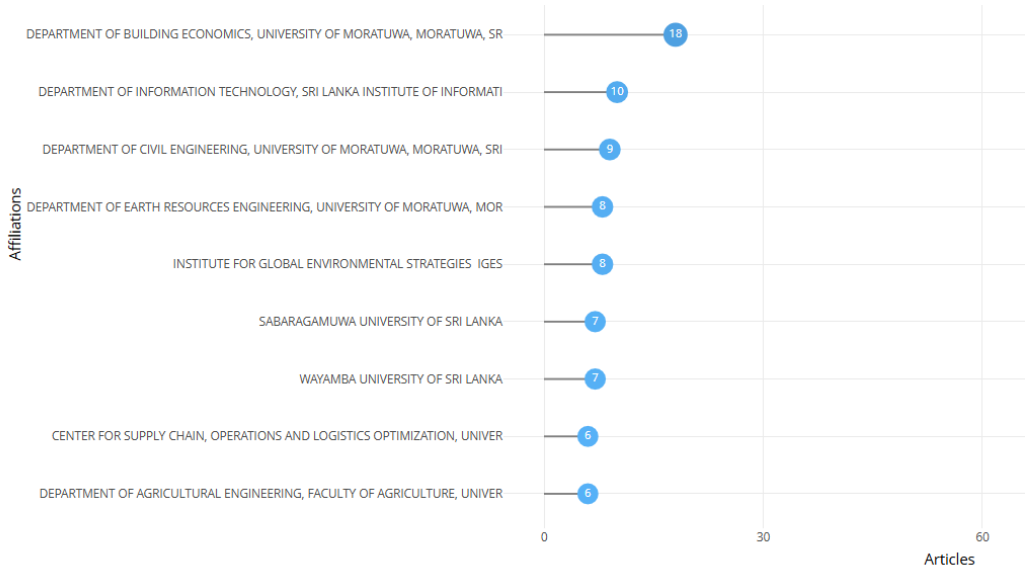

Figure 4. Most relevant affiliations
Source: output of Biblioshiny software

Future studies in waste management in Sri Lanka: trending research avenues

Keywords are crucial in representing a research article's core ideas and thematic landscape, serving as key indicators of research hotspots, themes, and evolving trends. In the context of waste management in Sri Lanka, keyword analysis utilizing techniques such as keyword clustering and keyword density visualization through tools like Biblioshiny can reveal underlying patterns within the field. The objective of keyword co-occurrence analysis is to examine the relationships between keywords in a set of papers to identify dominant topics and enhance scholars' understanding of current issues in waste management. By mapping these patterns, researchers can uncover significant trends and emerging focus areas within the field.

The treemap in this study visually represents the distribution of keywords related to waste management in Sri Lanka, with rectangle sizes indicating keyword frequency and colors denoting their categories or themes. Key observations include the prominence of keywords like "Sri Lanka," "refuse disposal," and "solid waste," which are central to the core themes of the research. The treemap also reveals clusters of related keywords, such as those concerning environmental issues, health, and social factors, illustrating the interconnectedness of different aspects of the topic. Larger rectangles represent more frequently used terms, while smaller ones indicate less common keywords. The treemap aids researchers in prioritizing relevant keywords to enhance their work's visibility and discoverability, selecting appropriate terms for indexing, and identifying emerging trends or shifts within the field by highlighting keywords with increasing frequency (Figure 5).

Figure 5. Tree mapping of the most relevant words used
Source: output of Biblioshiny software

The network visualization below visualizes relationships between waste management keywords in Sri Lanka, where each node represents a keyword, and the lines connect nodes based on their co-occurrence in the literature. Several key observations emerge from this visualization. Distinct clusters suggest areas of research or thematic perspectives that reflect varied emphases in waste management research. Thicker lines reflect strength and thinner lines have weaker associations among keywords. The node size of the keyword reflects frequency: the larger the node, the more frequent the use of that particular keyword. The main node is "Sri Lanka," so the principal concern is about this country, either with specific case studies or a more general overview of environmental issues in Sri Lanka. Key themes identified were: waste management, from terms such as "refuse disposal" and "solid waste"; the environmental impact, underpinned by keywords including "environmental monitoring" and "carbon footprint"; human health, represented through terms like "health" and "disease"; and social and economic concerns relating to developing countries and community participation. The network will assist in observing central themes based on understanding the relationships between

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keywords, hence serving useful insight into emerging trends in research on waste management in Sri Lanka (Figure 6).

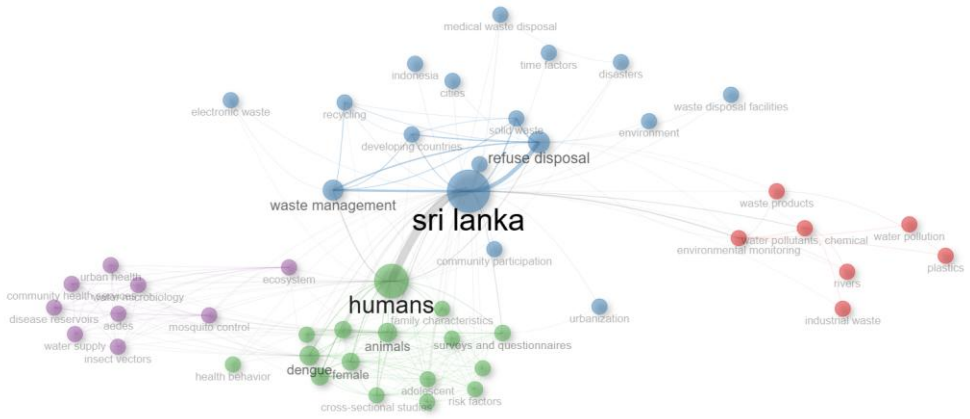

Figure 6. Keyword co-occurrence analysis
Source: output of Biblioshiny software

The thematic map of keywords for waste management in Sri Lanka, as depicted in Figure 7, provides a comprehensive view of thematic clusters based on their centrality and density metrics, highlighting the significance and interconnections of various research themes within this domain. One prominent cluster is "Sri Lanka," positioned in the upper right quadrant. This cluster represents a core theme with high centrality and moderate density. Keywords in this cluster, such as "Sri Lanka," indicate a strong focus on waste management issues specific to the region. This suggests that research is predominantly concentrated on waste management practices and policies within Sri Lanka, marking it as an essential theme in the field.

Another notable cluster is "Animals," which is also found in the upper right quadrant but has a higher density compared to the Sri Lanka cluster. This cluster includes keywords related to "Animals," "Cross-Sectional Studies," and "Dengue." The high density signifies an intensive focus on animal waste management, particularly concerning disease vectors like dengue. This indicates that a significant portion of research is directed towards understanding and managing waste related to animals and its implications for public health. The "Environmental Monitoring" cluster is located in the upper left quadrant, showing high density but lower centrality. Keywords such as "Water Pollutants" and "Chemical Waste Products" are central to this cluster, highlighting a crucial aspect of waste management research. The high density suggests that many studies focus on monitoring environmental contaminants, although this theme is less central than the main research themes.

In contrast, the "Disasters" cluster appears in the lower left quadrant, indicating lower centrality and density. It includes keywords like "Medical Waste Disposal," reflecting a focus on managing waste generated during disasters, particularly medical waste. The lower prominence of this cluster suggests that research in this area is less developed or not as central to the overall discourse on waste management.

Lastly, the "Electronic Waste" cluster is found in the lower right quadrant, exhibiting low centrality and moderate density. Keywords related to "Electronic Waste" suggest that this is an emerging study area, but it has not yet become a central focus within the research on waste management in Sri Lanka. The moderate density indicates some relevance, though it remains a less prominent theme (see Figure 7).

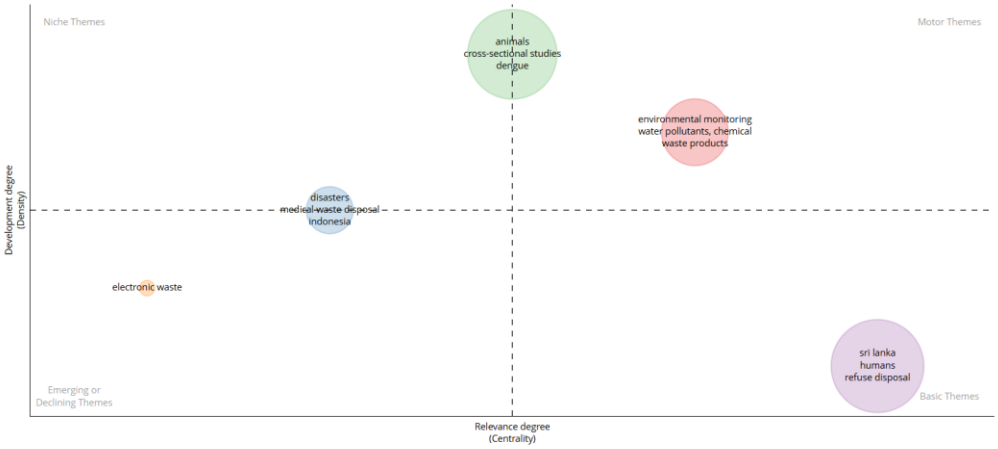

Figure 7. Thematic map of keywords
Source: output of Biblioshiny software

The keyword cloud for the study is represented in Figure 8. Considering that the research's topic is "Waste Management in Sri Lanka," it seems sense that "Sri Lanka" would come up most frequently. This high frequency indicates that waste management concerns unique to this location are the main emphasis of the research, reflecting its principal focus.

Figure 8. Keyword cloud
Source: output of Biblioshiny software

The central theme of "Waste Management" reflects its pivotal role in the studies, while terms such as "Environmental Monitoring" and "Solid Waste" emphasize critical aspects of overseeing environmental impacts and handling solid waste. The inclusion of terms related to the challenges faced by developing countries, such as "Developing Countries", and issues like "Animals," "Cross-Sectional Studies," and "Dengue," indicates a focus on animal waste and public health concerns, particularly related to diseases like dengue. "Recycling," "Surveys and Questionnaires," and "Water Pollutants Chemical" suggest an interest in waste reduction practices, research methodologies, and monitoring water pollutants. Additional terms like "Ecosystem," "Family Characteristics," and "Waste Products" reflect diverse aspects of waste management and its impacts. The mention of "Electronic Waste," "Medical Waste Disposal," and "Disasters" points to emerging topics that are gaining attention but are not as central to the research discourse as the more

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prominent themes. Overall, the keyword cloud illustrates a comprehensive focus on the specific context of Sri Lanka, encompassing various aspects of waste management, including environmental and public health issues and emerging topics within the field.

Trend topics

The trend topics plot offers insights into the evolution of research on waste management in Sri Lanka over time. Each dot on the plot represents a specific keyword or term, with its position indicating both the frequency of occurrence and the year it was most frequently used (Figure 9).

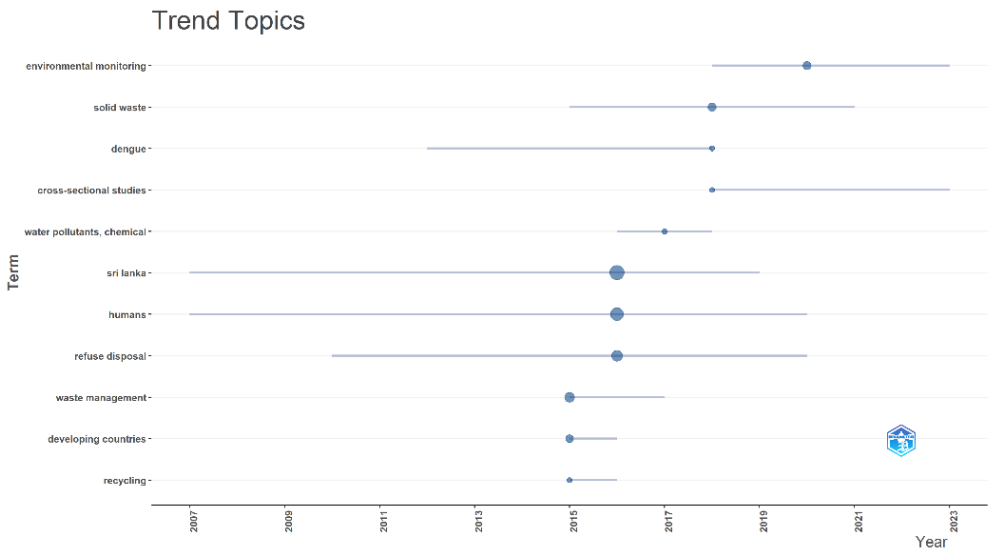

Figure 9. Trend topics
Source: output of Biblioshiny software

The plot reveals a steady increase in the frequency of terms such as "environmental monitoring" and "solid waste." This suggests that these topics have become increasingly important in recent research on waste management. Conversely, the term "dengue" shows a noticeable decline in frequency, indicating that it has become a less prominent focus in recent studies. This shift might reflect a decreasing emphasis on the relationship between waste management and dengue fever. On the other hand, terms like "cross-sectional studies" and "water pollutants, chemical" have maintained a relatively consistent frequency over the years. This stability suggests that these topics continue to be significant in the field of waste management research. The plot also reveals temporal patterns in keyword usage. For example, "Sri Lanka" and "humans" experienced a peak in frequency in the earlier years, while "refuse disposal" and "waste management" have become more prominent in recent years. These patterns highlight shifts in research focus and priorities over time.

Overall, the trend topics plot highlights emerging areas of interest, such as environmental monitoring and solid waste management, and provides insights into evolving research focuses. Understanding these trends and temporal patterns helps researchers identify relevant topics, recognize potential gaps in the literature, and contextualize the historical development of waste management research in Sri Lanka.

Conclusions

The holistic bibliometric analysis of waste management studies in Sri Lanka from 1970 to 2024 has been done with the support of OpenAlex database software and the use of Biblioshiny for finer details. The observations reflect several conclusions about the path of evolution and the present situation of waste management research in Sri Lanka. It shows a gradual increase in output with remarkable growth within this study period, starting from the early 2000s and up to 2024. Notably, 2020 can be seen as the peak in publication. This surge aligns with the growing intensified focus on Sustainable Development Goals (SDGs) that were introduced in 2015, where Sri Lanka is also a member state. In addition to that, the World Environment Day Forum 2018, organized by the University of Colombo in collaboration with a private organization that deals with hazardous waste, "Sri Lanka NEXT – A Blue Green Era (2019)," may have influenced the publication peak in 2020. Such an increase underlines the growing importance of waste management issues in Sri Lanka and covers an expanding body of knowledge in this critical area of waste management and circular economy. The key journals that have made major contributions to the research include "Waste Management" and "Journal of Material Cycles and Waste Management," while influential authors in their various works on building economics and construction management include Karunasena G, Amaratunga D, and Basnayake BFA.

Based on the results of the analysis of keywords and trend topics, research on waste management in Sri Lanka primarily focuses on animal waste, driven by public health concerns like dengue, by emphasizing its significant impact on disease transmission. Environmental monitoring focused on pollutants like water contaminants and chemical waste plays a supportive role in the future research agenda. Waste management in disaster scenarios, particularly medical waste disposal, is an emerging area, highlighting the need for tailored waste management strategies. E-waste management is gaining attention, signalling growing concerns about its persistent environmental and health risks as handling e-waste management is much more complex. This complexity of handling e-waste, combined with regulatory challenges and a lack of awareness among the public, hinders the expansion of the e-waste management industry at the national level (Ranasinghe & Athapattu, 2020).

Other trends, such as refuse disposal, highlight the methods and technologies used to handle waste effectively, reduce environmental impact, and ensure efficient waste collection and treatment systems. Another keyword related to waste management in Sri Lanka is Public awareness of waste management, which is a critical factor and is influenced by social and demographic factors (Swami et al., 2011). Meanwhile, waste reduction and electricity generation should be promoted in Sri Lanka, particularly through energy conversion techniques like incineration, gasification, composting, and anaerobic digestion (Samarasinghe & Wijayatunga, 2022). These techniques help transform municipal solid waste into renewable energy sources, producing heat, electricity, and other byproducts in an environmentally safe manner (Prajapati et al., 2021).

The study's findings reflect a research landscape that addresses both local challenges and global trends, emphasizing public health and environmental impact. The presence of the term "cross-sectional studies" highlights that the majority of the existing studies are based on cross-sectional studies. While cross-sectional studies are valuable, other research designs can offer deeper insights. Longitudinal studies examine long-term effects (Laird, 2022), experimental studies test specific interventions, such as policy interventions (Miller, Smith & Pugatch, 2019), and case studies provide in-depth lessons from different country regions. Surveys and questionnaires assess public attitudes (Berinsky, 2017), while action research engages communities in real-time solutions (Ozanne & Anderson, 2010). Systematic reviews and meta-analyses synthesize existing research to identify best practices and gaps in literature (Askie & Offringa, 2015). Combining these methods with

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cross-sectional studies yields a more comprehensive understanding of waste management challenges and solutions.

The bibliometric analysis revealed the evolution of trends and emphases of research related to environmental monitoring, solid waste management, and public health concerns. These themes portend major future research directions and areas of growing interest within the field. This study also epitomizes the role of international collaboration in enhancing the scope and outcome of the research on waste management. While this study has provided an overview of the developments and the present scenario in waste management research in Sri Lanka, several limitations need consideration. The analysis is restricted to data available through the OpenAlex database, with the scope limited to titles, abstracts, and keywords. Full text of articles may provide further insights into the area, as could additional databases such as Web of Science, Scopus, or Google Scholar.

Despite these limitations, the findings have significant theoretical and practical implications. The bibliometric analysis provides a thorough mapping of research trends, influential authors, and key journals that form a basis for future studies on waste management. Identifying highly visible research themes and areas of critical inquiry in the paper guides scholars, practitioners, and policymakers where their work can contribute most meaningfully towards current issues and to further the field.

The insights to be derived from this study would, therefore, facilitate the effort of narrowing the gap between theory and practice in waste management. Understanding these key themes will help researchers and practitioners facing pressing waste management challenges while also informing policy decisions toward developing strategies for waste reduction and effective management in Sri Lanka. In its entirety, it is a bounded value addition study about the benefit accruable from valuable knowledge enrichment of the field, setting the stage for further research and practical advances in waste management.

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