

Article

Bibliometric Analysis of Municipal Solid Waste Management Research: Global and South African Trends

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Abstract: Municipal solid waste management has become one of the most important environmental management issues around the world. In this study, a bibliometric analysis of the literature related to municipal solid waste management from a global and South African perspective was performed using the software, VOSviewer. Relevant scientific literature was sourced from the Scopus database. Results showed that, globally, articles based on this topic started during the 1968–1969 period, whereas in South Africa such articles only appeared in 1996. The keyword analysis showed that most studies were related to waste-to-energy technologies, waste treatment, and other management aspects. Globally, emerging keywords representing new research areas were COVID 19-related waste streams, life-cycle assessments, and the role of municipal solid waste management in the circular economy. In contrast, South Africa's prominent keywords were municipal solid waste, developing country, landfills, waste treatment, waste-to-energy technologies, pollution, greenhouse gas emissions, and others. Based on these results, and possible solutions to reduce the amounts of MSW generation rates, recommendations are made to bring South African research on par with international trends.

Keywords: literature review; municipal solid waste management; South Africa; analysis; scopus database; VOSviewer; clusters; themes; collaboration



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1. Introduction

Globally, the generation of municipal solid waste (MSW) is on the rise as a result of rapid population growth, increased economic development and industrialisation, urbanization, and growing consumerism in society [1–5]. The total MSW generated in Central Asia and Europe amounted to 392 million tons in 2016, and this amount is projected to increase to 440 million tons in 2030, thus representing an increase of approximately 11% [6]. North America generated about 289 million tons of MSW in 2016, and this is expected to increase by 21% in 2030. However, these amounts are relatively lesser in some of the developing regions. For example, the Sub-Saharan African (SSA) region produced only 174 million tons of MSW in 2016, with a projected growth of 269 million tons in 2030 [6].

MSW has a complex composition and usually emanates from households and commercial enterprises. MSW comprises different types of paper, bottles, plastics, as well as garden wastes, discarded foods, furniture, clothes, appliances, and even batteries [2,4,7–9]. To reduce the adverse and harmful nature of this waste stream, it is imperative to manage it effectively from its origin to the point of its final disposal or treatment or recycling. MSW is an intricate procedure and involves many steps, such as waste collection transport routes, temporary storage points, waste treatment, disposal, as well as energy recovery strategies, and recycling, the prime purpose being to enhance environmental protection, public health, and the need to comply with local government regulatory requirements [1,10,11]. Effective solid waste management is also one of the issues that are relevant in reaching the targets for the Sustainable Development Goal 11 of the United Nations, which involves working towards the attainment of sustainable cities and communities [12]. Similarly, Sustainable

Development Goal 12 seeks to ensure that member countries will substantially reduce their waste generation rates through prevention, reduction, recycling, and reuse of wastes [12].

In many of the developed countries, both national and local governments have succeeded in implementing effective measures to attain the goals of municipal solid waste management (MSWM), apart from a growing impetus towards waste minimization by means of treatment, recovery, and recycling. In Sweden and Denmark, major strides towards waste treatment and recycling have been achieved. Over 1.6 million tons of solid waste was landfilled in Sweden in 1975, whereas in 2012 this amount reduced to 32,000 tons, which is a significant decline that is traceable to effective legislation and regulation, enforcement of the polluter-must pay principle, waste separation at source by citizens, increased environmental awareness, economic incentives, and advanced technical and technological skills [13]. Moreover, of the 4.4 million tons of MSW generated in 2012, 51% was transformed into heat and electricity through combustion. In Denmark, 53% of the total waste generated is incinerated, 24% is recycled, and 18% is composted for the same reasons as in other Nordic countries [13]. Although Denmark has a very limited area, it is the greenest country as they are limiting land filling to 4% of the incoming MSW [14]. Implementation of environmental education, laws, and taxes have led to a reduction in landfilling and an increase in MSW recycling and energy recovery in Sweden [15]. Moreover, about 80% of the waste in Norway sent for incineration was used for energy recovery [16].

By great contrast, MSW is beset with many implementation challenges, institutional barriers, and the lack of finances and skills in developing countries. Reuse, recycling, and recovery policy in SSA has been slow, and land filling in dump sites remains a dominant way of disposing waste, especially in large urban centers due to poorly planned urbanization, and limited infrastructure [17]. Inevitably, urban areas in SSA are experiencing ineffective waste management because of generally poor municipal services. In addition, there is lack of MSWM and only 60% of the population receives collection services [17,18], thereby rendering the indiscriminate or illegal dumping of waste in the streets and open spaces in countries such as Nigeria and Malawi almost unavoidable [17].

Despite being a developing country, South Africa is one of the biggest producers of MSW in the world [2,17]. In 2012, South Africa generated approximately 108 million tons of waste, of which about 10% was recycled [17]. Therefore, low waste minimization is still a major challenge to be circumvented across many cities in the country. Effective waste management is constrained by several factors, such as rapid urbanization and the increasing influx of migrants into the major metropolitan areas [19], limited landfill space, discrepancies in the quality of MSWM between rural and urban areas as well as between townships, peri-urban areas and high-income residential settlements, lack of a skilled workforce, and poor implementation challenges [18].

In the light of the aforementioned literature findings, it can be seen that a literature analysis of the topic of MSWM requires increased prioritization and understanding, not only in the whole world, but also in South Africa where there are many implementation pitfalls, as well as limited institutional capacity and financial resources to deal with this problem. Because of this, it is essential to keep track of the geographical distribution of MSWM knowledge generation and research trends. One way to resolve this task is by conducting a bibliometric analysis of the existing knowledge on MSWM globally and in South Africa. Bibliometric analysis is a very useful tool to quantify such trends and distributions. However, it must be mentioned that the technique is not new and has been used since the 1970s, although it has gained more popularity in the present times [20]. The availability of various databases such as scopus, dimensions, and web of science have made bibliometric analysis relatively doable, and therefore it is not surprising to witness an increased proliferation of research into the mapping and analyses of knowledge landscapes and research priorities. Moreover, there is an increase in bibliometric analyses across many sectors such as the circular economy, energy supply and conservation research, construction, and the environment [20–31]. In this paper, a bibliometric analysis was

employed on selected keywords with the objective of determining trends, patterns, and gaps in the knowledge about MSWM.

2. Materials and Methods

2.1. Data Collection

The bibliometric analysis in the present study was derived from data in the scopus database. The MSWM keyword was used to extract data from this database. The search was done by considering article titles, abstracts, and keywords. However, some filters were applied to only include articles in English and from the Environmental Sciences discipline. However, no filter was applied on the year of publication, thus enabling a longitudinal trajectory in the study of this topic. In addition, only articles (including articles in press) were included. This process was repeated in a second search, but this time the search was limited to South Africa.

2.2. Data Processing

The data were then exported in the comma-separated values (CSV) format and further cleaned to remove duplicate entries, irrelevant articles, or articles with incomplete references. Subsequently, it was then viewed by VOSviewer as described by Sarquah [20].

2.3. Data Analysis

The number of articles, authors with the most publications, countries that are leading in scientific production, and the co-occurrence of keywords were amongst some of the parameters that were analysed using VOSviewer. The VOSviewer software is known for its high-quality visualization characteristics and end-user-friendliness. It also provides homogenous mapping and clustering of data (Figure 1) [32].

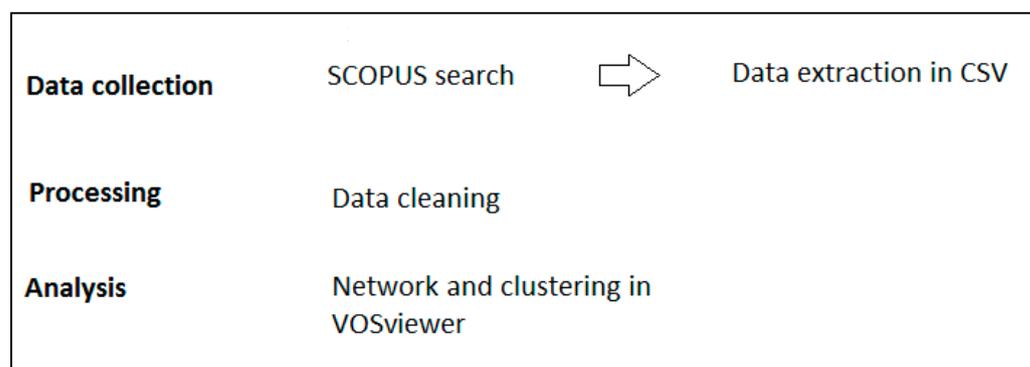


Figure 1. Summary of research methodology.

3. Results and Discussion

3.1. Municipal Solid Waste Management in the World

Based on the results obtained from the literature search and analyses, 7374 articles linked to MSWM were generated from the scopus database. Globally, in the following years—1968, 1969, and 1974—only one paper was published annually, respectively (Figure 2). However, from the year 1981 onwards, the number of published papers increased exponentially (Figure 2). This trend may be attributed to the rapidly growing importance of MSWM challenges that are facing many countries. Some European countries had to deal with challenges such as limited landfill space and the threat of environmental pollution on water bodies, climate change risks, and public health concerns [8]. Landfilling was no longer regarded as a viable strategy to deal with increasing volumes of MSW; therefore, alternative solutions had to be investigated, including waste minimization in the form of charging landfill fees, economic incentives, waste treatment, reuse, recovery, and recycling [14]. In a way, such a change in the direction of waste management was leading to the introduction of a circular economy (CE). According to Pires and Martinho [33], a CE

includes reuse, refurbishment, and remanufacturing, or reducing, reusing and recycling of waste materials [34]. In North America, working towards a CE has prioritized waste reduction over the traditional waste disposal by landfilling [35]. Similarly, there is also great impetus for the creation of the CE in countries such as China and Japan [11]. In some countries, the carbon footprint is used as a tool for evaluating the CE [36]. The recycling of mixed paper, plastics, and organic wastes in the industrial production of materials can reduce CO₂ emissions that are negatively implicated in global warming [37]. The analysis of academic articles on resource retention options showed some variations in the CE operationalization principle [38].

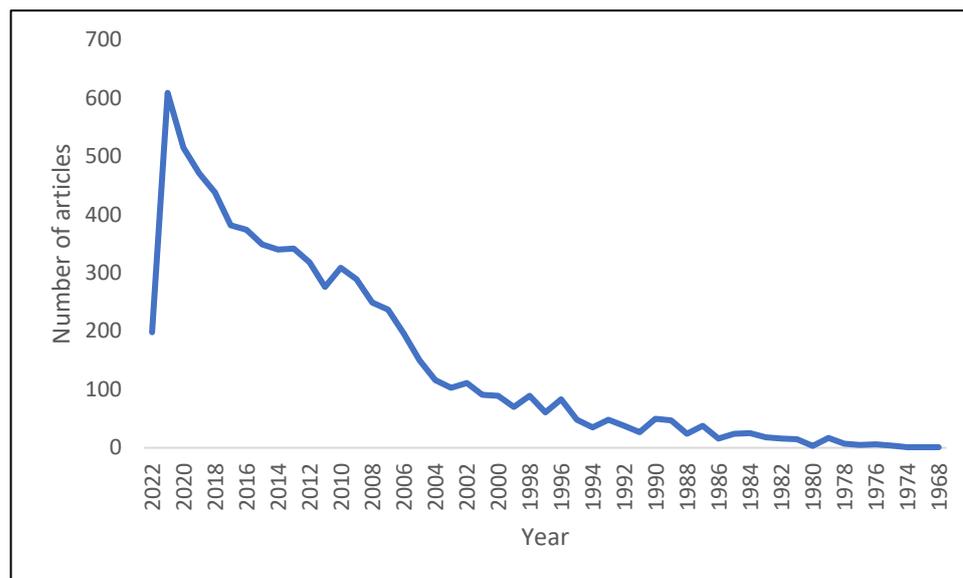


Figure 2. Growth of articles over a 54-year period.

The individual performance of countries is shown in Figure 3. Nearly 137 out of 195 countries have contributed to the body of knowledge focused on MSWM. Notably, some of the countries within this 137 are developing countries such as Ghana, Malawi, Namibia, Rwanda, and Senegal, although they were contributing only one article each. However, countries in the developed regions have contributed the most in the existing body of MSWM knowledge (Figure 3).

In total, 201 countries have contributed to the existing research on MSWM. However, only 113 countries had a minimum of at least two research outputs (Figure 4). Countries with the greatest number of contributions are the USA (1004), China (976), Italy (593), Spain (434), UK (366), Canada (359), and Germany (266). Other articles came from developing countries such as India (592), Iran (179), Thailand (131), Nigeria (72), South Africa (61), and Indonesia (44) (Figure 5). Some of the countries with the least number of publications were North Korea and Congo with three and two documents, respectively (Figure 4).

Based on the results, a high number of documents per country does not necessarily mean high citations (Table 1). In this study, only seven out of the fifteen countries with most documents had higher citations. For instance, the USA had 1004 publications with approximately 35,206 citations. Similarly, China's 976 documents attracted 29,062 citations. Italy's 593 documents had 20,200 citations, meanwhile India's 592 articles had 13,196 citations. By contrast, Spain, UK, Germany, France, Sweden, Iran, and Australia had relatively lesser publications but more citations (Table 1).

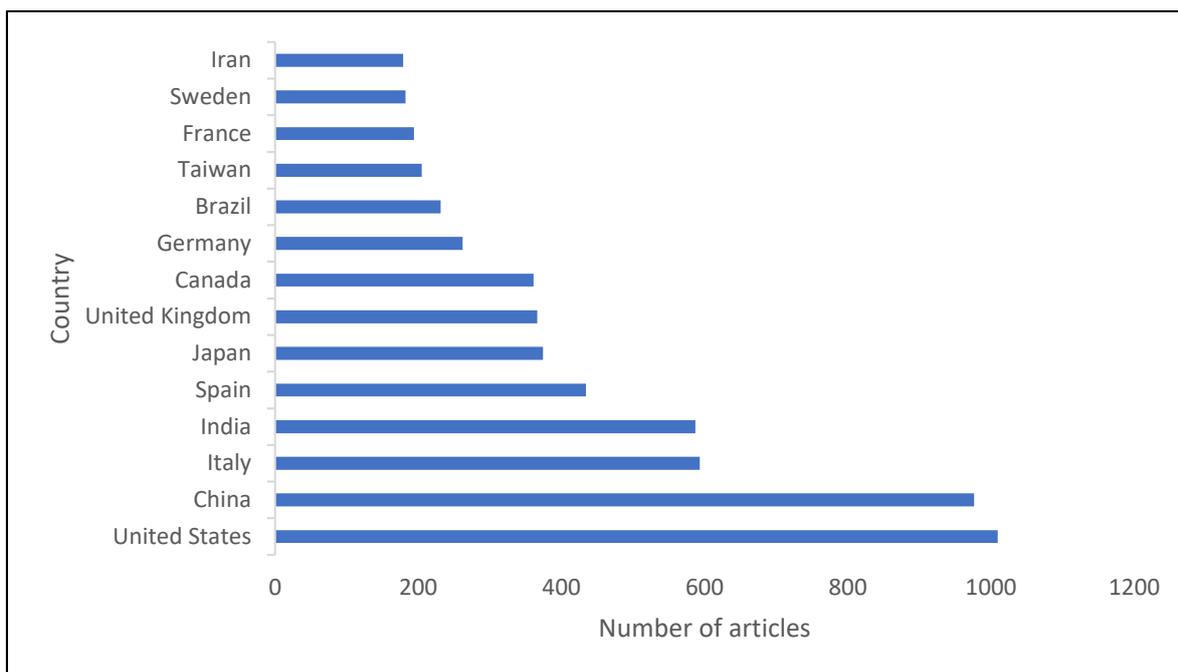


Figure 3. Top fourteen countries with the most scientific publications on MSWM.

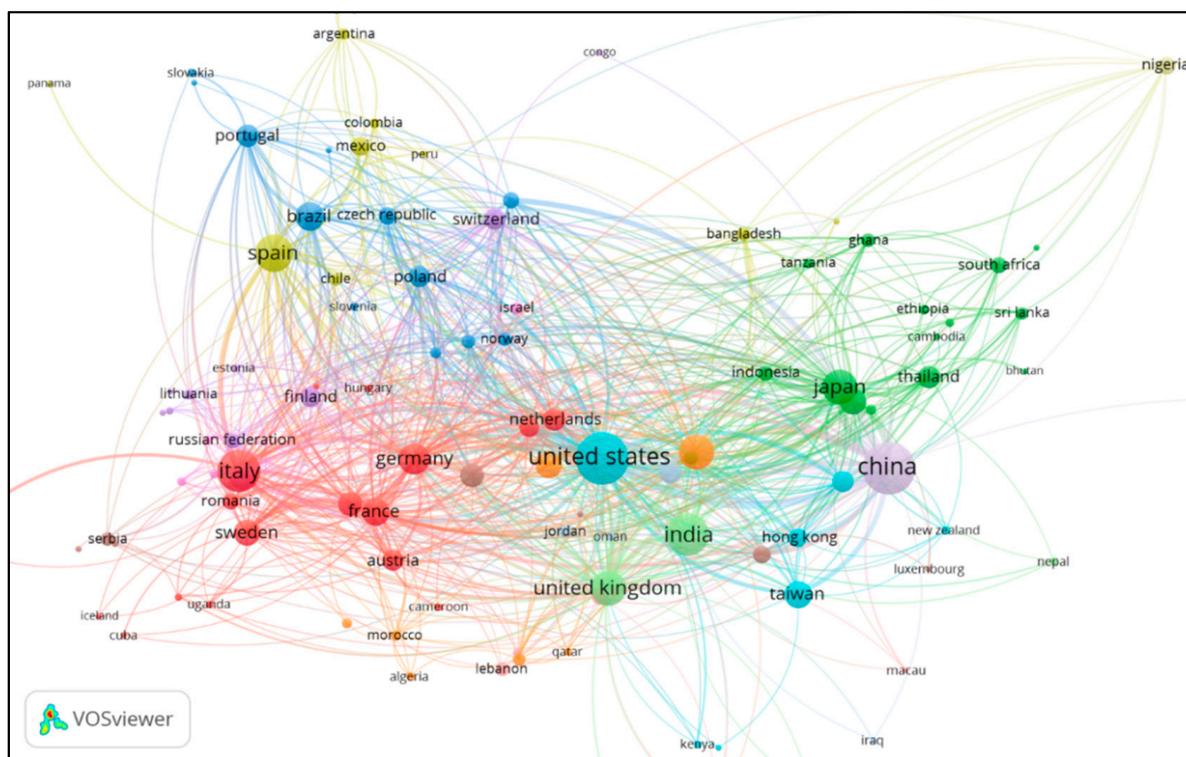


Figure 4. Co-authorship network based on countries. Criteria of at least two papers per country was used and out of 201 countries, only 113 met the threshold. A total of 110 connections are shown.

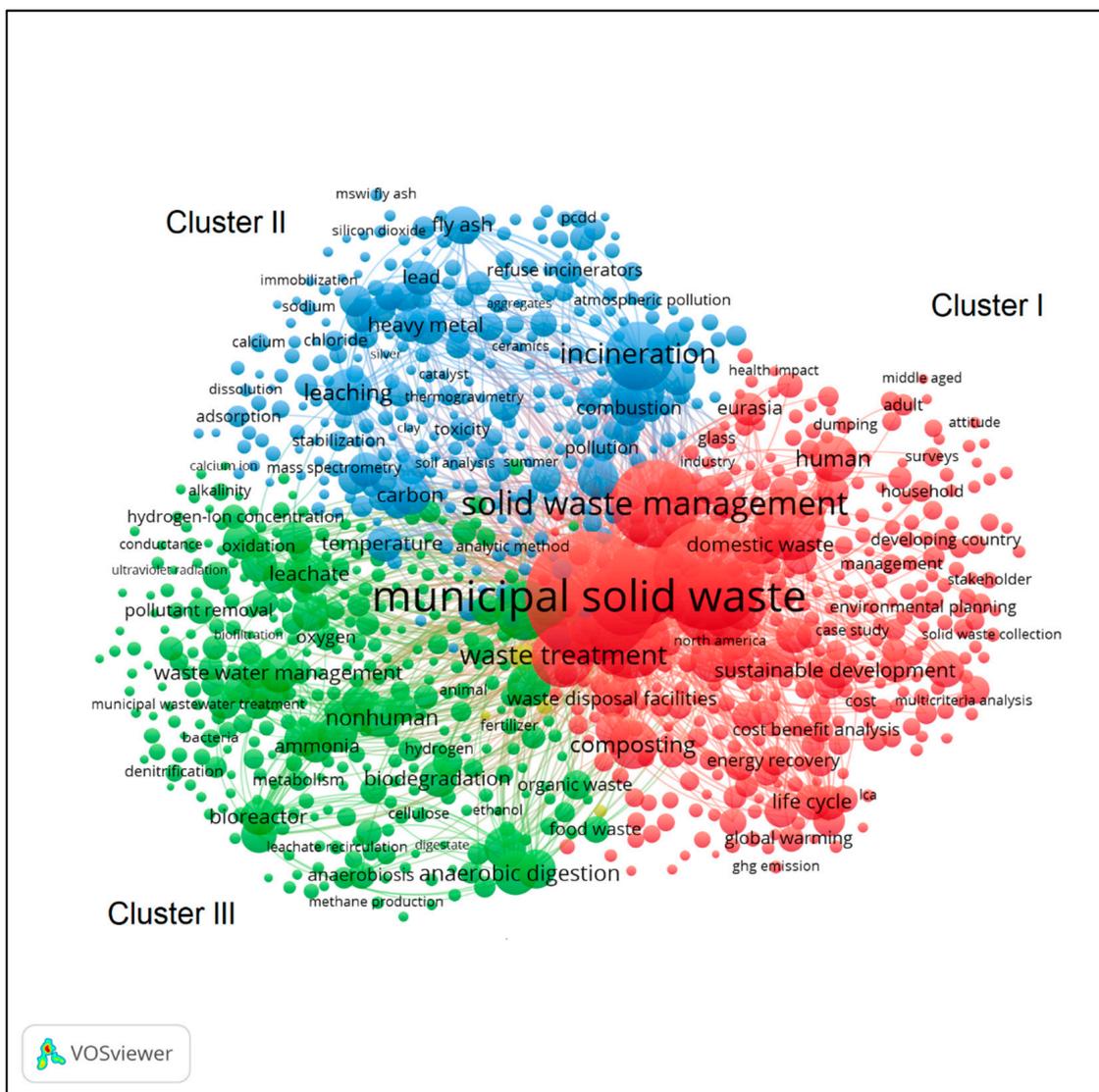


Figure 5. Co-occurrence of keywords. Keywords that appear a minimum of five times are shown. Out of 32,726 keywords, 5429 words met the threshold.

Table 1. Top fifteen countries with the most scientific articles and citations.

Country	Articles	Citations
United States	1004	35,206
China	976	29,062
Italy	593	20,200
India	592	13,196
Spain	434	17,323
Japan	373	12,059
United Kingdom	366	13,321
Canada	359	10,043
Germany	266	10,183
Brazil	231	4262
France	194	6941
Sweden	182	8617
Iran	179	4688
Australia	175	5395

The size of the circle or the circumference of the spheres in Figure 4 is dependent on the number of the occurrence of certain keywords [39]. In Cluster I, Italy has the biggest circle. In Cluster II, Japan has the biggest circle. The biggest circle in Cluster III, IV, V, VI, VII, VIII, IX, X, and XI belong to Brazil, Spain, Switzerland, Turkey, Iran, China, India, Israel, and the USA, respectively. Saudi Arabia and Malaysia had the biggest circles in Cluster XII and XIII (Figure 4).

In terms of research linkages or collaborations with other countries, the USA and the United Kingdom (UK) had most linkages with 64 and 63 other countries, respectively. They were followed by China (59), Germany (55), India (50), Italy (47), France (42), Spain (39), Canada (37), and Japan (36). The 64 links observed for the USA were between countries such as France, UK, Japan, Netherlands, Germany, India, Turkey, Canada, and South Africa. Interestingly, among these countries, the UK had the highest links (63) (Figure 5). Linkages were observed between USA, Australia, China, and India. Notably, some links were also found between Bangladesh and Thailand. Spain was linked to countries such as Argentina, Poland, Czech Republic, Portugal, and Mexico (Figure 4).

Furthermore, Bangladesh, Thailand, Saudi Arabia, and Malaysia collaborated on COVID-19-related personal protective equipment (PPE) waste research [40]. They have suggested incineration to reduce the increase in PPE wastes. Researchers from Canada, North Korea, and the USA investigated the potential of converting cardboard waste into lactic acid. Thus, cardboard waste can be an important source for producing lactic acid and has associated economic benefits based on technoeconomic analysis [41]. Since cardboard forms part of MSW, this study is of particular interest because waste conversion practices and resource recovery are very important for a sustainable bioeconomy.

Researchers from Sri Lanka and India developed a user interface tool that uses Google Earth to establish spatial information relevant for the siting of alternative dumping sites [42]. The Chinese–North Korean collaboration has created a model for urban biowaste management. The model performed optimally, and important policy recommendations were suggested [43]. Poorly planned urbanization is linked to illegal solid waste disposal and water pollution. This promoted a rapid impact assessment matrix for urban water shed management by researchers from Brazil and Canada [44]. Their results showed that by using rapid impact assessment matrix, the negative impacts on urban water streams as a result of urbanization can be reduced. The Japanese–Thailand collaboration has investigated the effects of compost bin design, design preference, waste collection performance, and their data clearly showed that appropriate bin design increased the effectiveness of waste recovery rates [45].

A total of 32,726 keywords were generated during the literature review. The threshold used was a minimum of five occurrences per keyword; the most dominant keyword was “MSW” which appeared 5842 times, followed by “waste management” and “solid waste management” which occurred 4199 and 2634 times, respectively (Figure 5).

The keyword analysis revealed three distinct Clusters. The three keywords mentioned above fall under Cluster I (Figure 5). In Cluster I, MSWM is closely linked to efforts towards the achievement of sustainable development goals. Some important research on MSW in Cluster I focused on life cycle assessment (LCA) of MSW [46], promotion of MSW recycling in the developing countries [47], and the contribution of MSW towards greenhouse gas emissions [48]. Some of the key findings from such studies were that a balance between landfill and incineration was the optimal waste management option [46].

Cluster II keywords were largely made up of words such as “chemical elements”, “incineration”, and “pollution abatement”. In Cluster II, the transformation of hazardous elements in ash from waste incineration plants was investigated [49], and using integrated strategies for MSWM may lead to a reduction in greenhouse gas emissions by 2050 [48].

Cluster III was largely occupied by “anaerobiosis”, “anaerobic digestion”, “bioreactors”, and the “management of sewages” (Figure 5). Some of the key research in Cluster III involved the environmental impact assessment of the organic fraction from MSW treatment by anaerobic digestion [50]. Anaerobic digestion transforms organic matter to biogas and

sludge under anaerobiosis. The process is effective in reducing greenhouse gas emissions, and the resultant biogas can be used as a renewable energy source. Moreover, the resulting digestate can also be used as fertilizer to improve soil quality [50]. In Cluster III, “pollutant removal” and “wastewater treatment” were closely linked. The elimination of toxic chemicals from wastewater is one of the strategies to help reduce the environmental impacts of such waste materials [51]. Leachate contamination of water also poses a significant public health risk [52].

The Clusters also show the different research streams under MSWM (Figure 5). Some of the research streams involved refuse-derived-fuel (RDF). RDF appeared 38 times and some research looked at policy options for sustainable RDF production [53]. RDF production is regarded as a substitute for using fossil fuels along with its associated environmental benefits [53]. Computer modelling and machine learning appeared 28 and 19 times, respectively. Another research strand involved developing multi-city models for MSW generation predictions by Lu et al. [54] and Zhang et al. [55]. The results by Zhang et al. [55] showed that population and GDP are two of the most important indicators in MSW prediction. Similarly, key factors influencing MSW generation are annual precipitation, population density, and mean annual temperature [54]. This is because precipitation increases the moisture content of MSW, thus increasing the total weight. In addition, high precipitation and temperature also influences human behavior, hence the consumption of goods and services. High precipitation may also contribute to increased crop production, thereby leading to more organic waste generation, whereas high population numbers are linked to more waste items being produced per person.

The occurrence of keywords from the year 2002 to 2022 is shown in Figure 6. There are few emerging topics, and they are shown by the yellow color (Figure 6). Some of the newly emerging research involved COVID-19-related wastes, CE, and attendant constraints. In fact, COVID19 research appeared 47 times and it examined the health-care waste associated with the COVID-19 pandemic [56]. Some of the key research led to the detection of the SARS-CoV-2 RNA in MSW leachate [57]. Detecting the COVID-19 viral RNA in MSW leachate is useful when there is no adequate treatment system and sanitation infrastructure [57]. The general key finding in some of the COVID-19 studies was that health care waste and its management increased during the pandemic [56].

Words that appeared many times during the year 2015 (shown in light green) included China and waste disposal (Figure 6). The reason why the word China had high incidence could be attributed to the increased research conducted in that country since 2015 to the present. Important research topics included the following ones: (1) sustainable waste management and waste-to-energy projects [58]; (2) changing city-level greenhouse gas emissions from MSW treatment and driving factors [59]; (3) comprehensive emission inventory of hazardous air pollutants from MSW incineration [60]; and (4) how can waste management contribute toward the development of a greenhouse gas sink [61]. Other researchers examined the identification of suitable, future waste disposal sites using the analytic hierarchy process (AHP) and geographic information systems (GISs) [62,63], and a quantitative analysis of MSW disposal charges in China [64].

3.2. Municipal Solid Waste Management in South Africa

Generally, in South Africa, the articles published annually during the 1996–2021 period have never exceeded ten (Figure 7). Although the highest number of articles (8) were published in 2020, only one article was published in the following years, 1996, 1997, and 2004, respectively (Figure 7). From then, the number of articles increased, but dropped dramatically in 2008 probably due to the after-effects of the global financial crisis, which could have affected research funding and research priorities in a negative manner. Therefore, in 2008, only one paper was published compared to two from the previous year. Later, there was an increase in articles as from the year 2010 to 2013 and during the 2015–2019 period, largely due to the increasing attention being paid to MSWM and how it

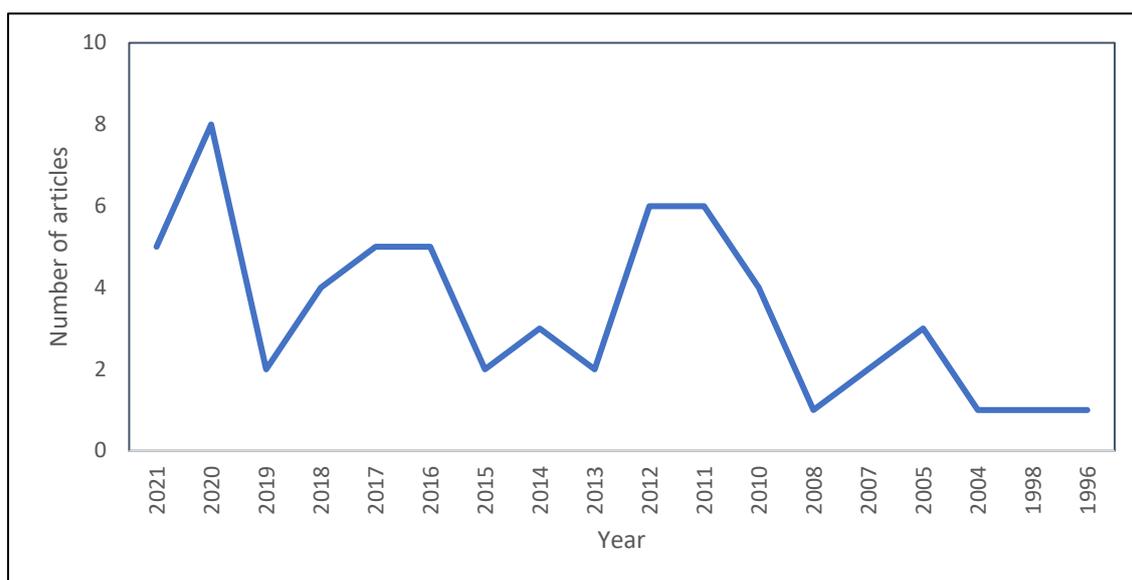


Figure 7. Growth of articles over the years.

Table 2. Institutional contributions towards the publication of scientific articles in South Africa.

Institution	Number of Articles
University of KwaZulu-Natal	19
University of the Witwatersrand	13
University of Johannesburg	10
University of Cape Town	6
The Council for Scientific and Industrial Research	5
Stellenbosch University	3
Walter Sisulu University	3
North-West University	3
University of Venda	3
Tshwane University of Technology	2
University of the Witwatersrand Faculty of Health Sciences	2
Environmentek	1
Green House	1
uMoya-NILU Consulting	1

In the SADC region, South Africa was central in terms of research collaborations as it exhibited seven research links with other countries in the world (Figure 8). All the other countries had one link or collaboration, except for Ethiopia and the UK which had two links. This is because the search was limited to South Africa. Based on Figure 8, there were a total of five different Clusters. In Cluster I, the most important countries are Canada, China, and South Africa. The UK and Ethiopia are featuring prominently in Cluster II. In Cluster III, IV and V, Australia, Botswana, and France came out to be the most important countries (Figure 8). Although a total of seven countries have collaborated with South Africa, the biggest collaborator is the UK. Researchers from both countries modeled greenhouse gas emissions from MSW disposal across Africa [65], assessed air quality management in South Africa [66], and evaluated leachate recirculation with cellulase addition to enhance waste biostabilisation and landfill gas production [67].

Although most countries that collaborated with South Africa had nearly an equal number of research outputs, the citations varied greatly. Australia and Botswana had three documents each with 63 and 54 citations, respectively. China, France, Ethiopia, and Canada had two documents with 51, 22, 21, and 18 citations, respectively. In addition, the UK and South Africa had 60 and 6 articles, respectively, with 995 and 118 citations, respectively (Table 3).

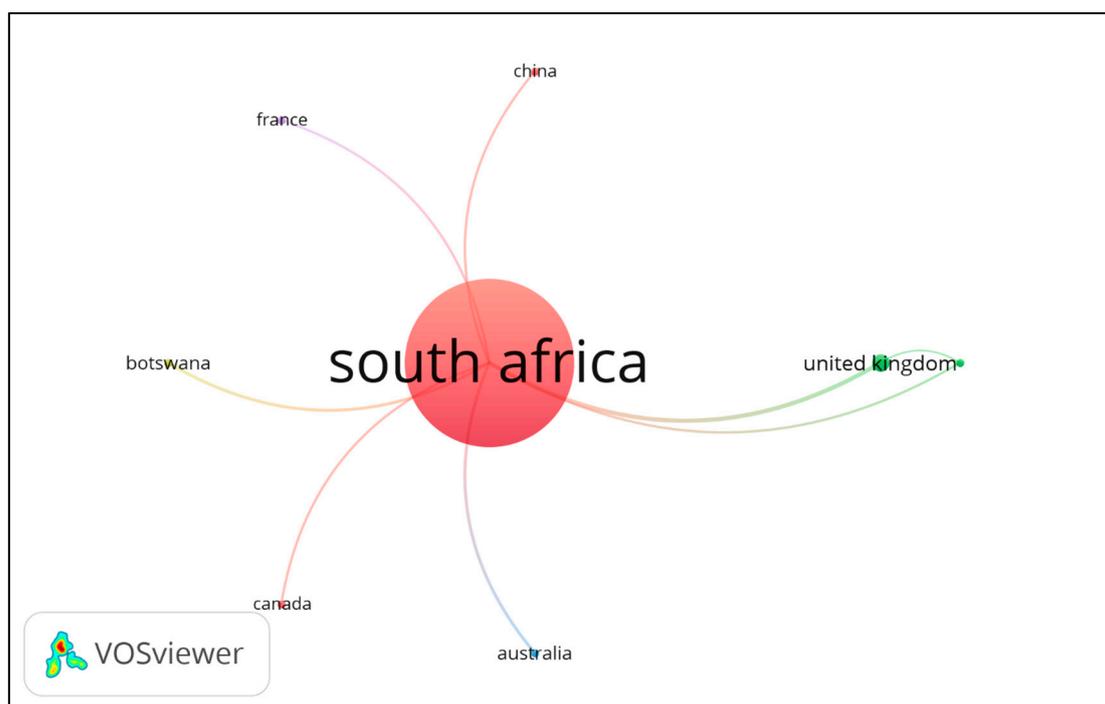


Figure 8. Co-authorship network based on countries.

Table 3. Countries that collaborated with South Africa.

Country	Articles	Citations
South Africa	60	995
United Kingdom	6	118
Australia	3	63
Botswana	3	54
Ethiopia	2	21
Canada	2	18
China	2	51
France	2	22

The network visualization in Figure 9 shows three main Clusters associated with MSWM. MSWM is closely associated with landfill sites (Figure 9). The aforementioned words are found in Cluster I. The word “MSWM” appeared 45 times, followed by “waste disposal” and “solid waste management” which occurred 44 and 26 times, respectively. Furthermore, the words leachate treatment, leaching, and sewage also appeared in Cluster I. The effect of cellulase to enhance waste biostabilisation and landfill gas production has been investigated. Cellulase augmentation to leachate was found to be economically viable [67]. The use of organic wastes for the denitrification of landfill leachate showed the suitability of organic MSW to sustain denitrification, thus offering a low-cost method for alternative landfill treatment [68]. Determining pollutant concentrations after long-term leaching showed that water flow needs to be taken into account in order to improve leachate quality and quantity [69].

Cluster II is characterized by studies on the greenhouse effect, carbon dioxide (CO₂), and other gas emissions. The ways in which greenhouse gases are accounted and reported in the waste sector in South Africa were studied and different accounting methodologies were identified [70]. Greenhouse gas emissions from the management of MSW in the eThekweni Municipality were investigated by Friedrich and Trois [71]. The results showed that MSW recycling can help to prevent the emission of approximately 113,275 tons CO₂ by replacing virgin materials with recycled materials. Furthermore, the modelling of

greenhouse gas emissions from MSW disposal has indicated that such releases will increase in Africa and will further contribute to climate change [65].

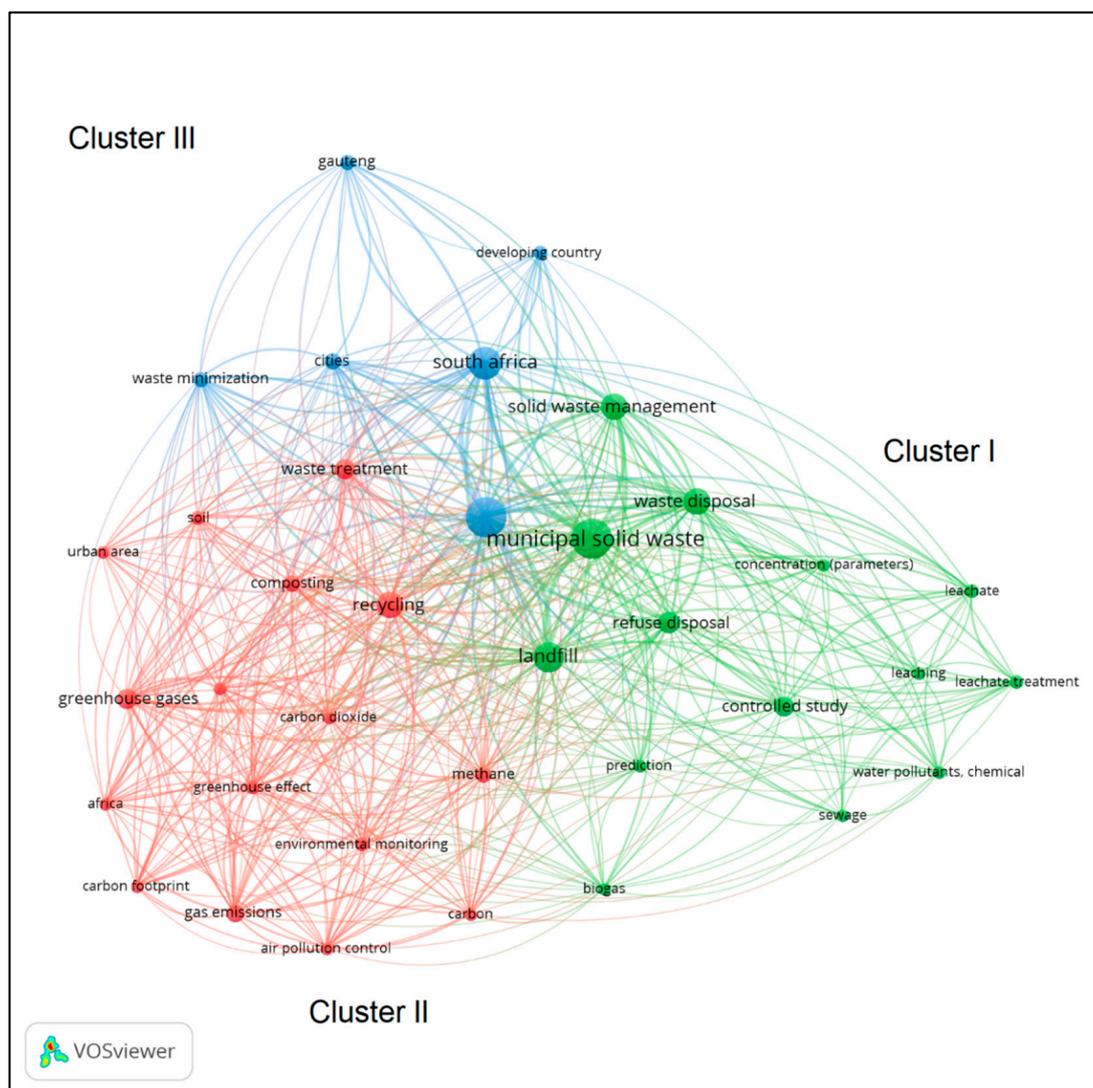


Figure 9. Co-occurrence of keywords in South Africa.

Cluster III is characterized by research themes covering the Gauteng province, despite the literature being open to the whole of South Africa. Key studies have focused on sustainable solid waste management in developing countries with emphasis on Johannesburg [17]. For example, two research areas which received attention included: waste-to-energy recovery in Johannesburg [72], and spatial and temporal variations in the microbiological pollution occurring in the Vaal River of South Africa [73]. Other findings indicated that landfill airspace in Johannesburg will be depleted by the year 2023 [72]. The least commonly appearing key words were “urban area” and “sewage”, which featured 25 and 20 times each. The articles on sewage management do not seem to be emerging topics because some of the topics were published as early as 2010 and 2017 [74,75].

Based on Figure 10, there are no new emerging topics since the year 2020, and this is deduced from the absence of keywords in yellow. However, some words which had a high incidence around the year 2015 included “MSW” and “developing country” (Figure 10). The studies on those keywords included: co-operatives as a development mechanism to support job creation and sustainable waste management in South Africa [76], sustainable solid waste management in developing countries, and studies of the institutional factors

Lastly, another important research area entailed the composition of MSW, which is dependent on where the waste is coming from, thereby raising the potential for informing local waste management systems so that effective waste recovery is achieved [79,80]. At the University of Venda in the Limpopo province, it was found that the proportion of compostable wastes relative to other waste types was greatest in the student residences and kitchen facilities (40.6% and 40.5%), respectively [79]. This reveals an untapped potential for recycling such wastes at this university; an opportunity that can help in reducing the volume of prevailing waste streams. Furthermore, Nell et al. [81] have examined the composition of wastes from illegal dumpsites in a rural town in the Northern Cape province. Their study found 17 different waste fractions, of which some of their weight comprised garden waste (4%); glass (13%); recyclable plastics (15%); paper and cardboard (13%); and e-wastes and other household hazardous wastes (1%). In light of these results, it is imperative that municipal planning to minimize illegal dumping must take the needs and perceptions of local communities into consideration regarding their infrastructure problems [81].

3.3. Possible Solutions to Reduce MSW

As MSW generation continues to increase at an alarming rate globally, the environmental pollution caused by this waste stream has become a growing public health concern. There is, therefore, an urgent need to improve municipal waste management practices and the implementation of associated policies [82]. Existing literature shows that there are many ways to reduce MSW generation rates, and in this section, waste-to-energy generation and household waste segregation are put into perspective for reducing the management burden of MSW.

The utilisation of waste for the generation of energy may contribute towards their reduction and possible elimination. Waste-to-energy (WTE) generation refers to a waste treatment process that produces heat and energy from various waste sources, including MSW [83]. The process can be conducted by means of thermochemical processes such as incineration, pyrolysis, and gasification, or biological processes which entail biomethanation as well as composting [84]. The effective utilization of these technologies is contingent upon several factors, including the specific attributes of the waste feedstock, access to funding opportunities, and environmental aspects [85]. Across the globe, more than 1700 WTE plants have been established and the bulk of them are located in Asia Pacific (62%) and Europe (33%), while North America has few of them (4.5%) [85]. In South Africa, various WTE plants have been started in some of the metropolitan municipalities in provinces such as KwaZulu-Natal, Western Cape, and Gauteng [86]. For instance, in the Gauteng province, several landfill gas projects were commissioned in 2016 for enhancing both environmental and public health benefits. Despite their implementation challenges, especially the high operational costs, their potential energy output was estimated to be 8000 MWh yr⁻¹. When connected to the national electricity grid, such energy generation is expected to provide electricity to nearly 25,000 middle-income households [87]. There is, therefore, a need for appropriate policy adaptation in South Africa to curb existing challenges as the country has the highest theoretical potential of energy generation from MSW [88].

Another effective solution to reduce waste generation at the municipal level is by encouraging waste reuse and recycling. In Denmark, between the years 1993 and 2018, the recovery of municipal wastes has risen from 80% to 99% while composting increased from 9% to 17% [89]. On the other hand, landfilling declined from 20% to 1% [89]. These remarkable achievements can be ascribed to many years of investing resources, infrastructure, and intervention strategies into their waste management sector, thus providing useful lessons for other countries to learn. In addition, the recycling processes are not achievable without the participation of citizens in the segregation of wastes at home. Therefore, it is imperative to provide communities with relevant information, feedback, and incentives so that they can participate meaningfully in waste reclamation and recycling [90]. In Singapore, it was found that household knowledge of what wastes are recyclable played a very important

role in their waste minimization strategy [91]. Similarly, in South Africa, residents in urban areas are constrained to participate effectively in household waste segregation largely because of inadequate space, lack of time and recycling knowledge, and inconvenient recycling facilities [92]. Hence, one of the recommendations suggested for increased household waste sorting in Johannesburg (South Africa) is to simplify household waste separation so that it is convenient to residents across all age groups [93].

Lastly, since food waste is one of the biggest contributors of MSW and constitutes more than 50% of this waste stream, it is important to treat it accordingly. Therefore, to curb the increase in household kitchen waste, source separation followed by treatment is recommended [82]. Furthermore, anaerobic digestion can be applied, thus reducing its environmental impact by over 51% [93]. Fei et al. [82] also suggested the use of food waste disposers (FWDs) since they can result in significant waste reduction. Designing on-site biochemical food waste treatment plants was identified as another waste reduction option, provided there are large amounts of food wastes to be brought to such treatment plants. Furthermore, food waste can be reused as animal food and a source of compost to support agricultural activities [94].

3.4. Summary of the Literature Trends

Table 4 indicates a comparative overview between MSWM at a global level and at a South African level. Based on the search criteria followed in the present research, research publications on MSWM amongst different countries or at a global stage started in 1968 with only one publication. During the 1970–1973 period, no article was published. However, as from 1974, some work was being published. In 1979, 17 articles were published and from then, the number of papers increased exponentially and reached a high of 626 articles in 2021. This rapid increase may be ascribed to the growing attention being given to MSWM challenges globally. On the other hand, in South Africa, publications only started relatively late as one publication was published in 1996 and such papers never exceeded eight in any given year. Moreover, the 17 articles published globally in 1979 surpassed the total number of articles published in South Africa between 1996 and 2022. Similar to the global trends, there was a period in South Africa when no articles were published (1999–2003), although they resumed in 2004. In South Africa, the highest number of articles published in 2020 was seven. A total of 159 authors worldwide have contributed about 7374 scientific articles with a focus on MSWM, whereas in South Africa 145 authors have contributed 60 scientific documents.

Table 4. A comparison of trends in MSWM research in the world versus South Africa.

Municipal Solid Waste Management Trends	World	SA
Total number of articles	7374	60
Authors	159	145
Affiliations	168	61
Highest number of publications by author	83	11
Least number of documents by author	8	1
Highest number of papers since publications started in a given year	626	7
Keywords	37,276	1194
Emerging topics in the 2020s	3	0

The emerging keywords at the world perspective during the 2020s were COVID-19 waste research and CE, electronic waste, research based on China, waste disposal facilities, organic wastes, sewage waste treatment, and associated health issues. In South Africa, MSWM research in terms of the circular economy and COVID-19 challenges is lacking. By contrast, the most prominent keywords for MSWM research in South Africa are urban area, developing country, MSW, methane emissions, and landfills. Documents relating to electronic waste in South Africa were lacking amongst the 60 papers mentioned in Table 4.

Globally, there was a total of 37,276 keywords related to MSWM research. Some of the most dominant keywords that occurred more than 1000 times in descending order were MSWM, waste management, solid waste management, waste disposal, refuse disposal, solid waste (solid wastes), landfills, incineration, recycling, waste treatment, and waste incineration (Table 5). The least occurring keywords that appeared less than ten times included waste reuse, sustainability indicators, MSW generation rates, radiation waste, waste collectors, and food waste disposers.

Table 5. Most frequent keywords in the world and authors.

Keywords	Examples of Literature Sources
Municipal solid waste management	[2,4,11,14,16,37,46,48,54,59]
Waste management	[13,33,58,61]
Solid waste management	[15,95]
Waste disposal	[62–64,96]
Refuse disposal	[97,98]
Solid waste (solid wastes)	[59,96]
Land fill (landfill)	[68,96]
Incineration	[56,60,96,99]
Recycling	[100]
Waste treatment	[59,101]
Waste incineration	[56,99]

In South Africa, there was a total of 1194 keywords related to MSW research. Except for waste incineration and gas emissions, the words were almost identical. Some of the most dominant keywords in South Africa that occurred more than ten times were MSW, waste management, waste disposal, refuse, solid waste (solid wastes), landfill, recycling, waste treatment, and gas emissions (Table 6). The examination of the 60 articles in South Africa showed that studies on waste incineration or incineration are missing. In contrast, the least occurring keywords did not exactly match up to the global trend. The words that appeared the least were: waste-to-energy technologies, bioenergy, biological water treatment, sustainable development goals, leachate recycling, waste companies, anaerobiosis, and food waste disposers.

Table 6. Most frequent keywords in South Africa and authors.

Keyword	Authors
Municipal solid waste	[65,71,72,77]
Waste management	[71,76,78,102]
Solid waste (solid wastes)	[17]
Waste disposal	[74,103]
Refuse	[104]
Land fill (landfill)	[67,87,96,105]
Recycling	[79,106]
Waste treatment	[102,107]
Greenhouse gas emissions	[69]

4. Conclusions and Recommendations

This paper conducted a bibliometric analysis of the available scientific literature on MSWM at a global level and from a South African perspective. With such analyses, it was possible to determine existing patterns and trends in the research about MSWM while revealing similarities and dissimilarities at a global stage and within a South African context. Based on the results generated, the following conclusions and recommendations are summarized.

Although the MSWM research started as early as 1968 from a global perspective, in South Africa such research focus only started in 1996. This discrepancy shows that

MSWM research at an international level is ahead of South African contributions. The pattern is partly driven by differences in situational contexts, whereby MSWM issues were given much attention quite early in the developed countries largely because of the inherent environmental and health risks associated with MSW landfilling. For example, in the USA, the MSWM research around 1968 was pre-occupied with the challenges presented by unrestrained municipal waste generation and the extent to which landfilling was constrained by a lack of new spaces, especially in the urban areas, and the potential for environmental pollution [108]. At that time, the incineration of municipal waste was seen as a viable solution to reduce the volume of waste generated in the urban areas but with rising health concerns due to gaseous emissions [108]. The same MSWM issues involving emissions received research attention in South Africa, but this occurred much later during the 1996–2004 period. At that time, much research effort went into the understanding of the different chemical pollutants that were in gaseous emissions and the leachate produced by waste decomposition [104,109,110].

At an international level, the total number of research outputs, keywords relevant to MSWM, and the number of collaborations were relatively more for developed countries than is the case in South Africa. Globally, the research clusters consisted of keywords such as WTE technologies, sustainable development, circular economy (CE), and life-cycle assessment (LCA). On the other hand, the research clusters in South Africa consisted of MSW, landfills, waste treatment, WTE research, microbiological pollution, waste management cooperatives, and greenhouse gas emissions. These discrepancies in MSWM research indicate differences in research priorities and capabilities. This shows that more resources should be allocated to South African MSWM research so that it can be on par with international trends, especially in comparison with developed countries. Therefore, more research prioritization and funding are recommended in South Africa for the following research topics:

- Role of MSWM in meeting sustainable development goals;
- Life-cycle assessment of MSW;
- Implementing integrated strategies for MSWM;
- Computer modelling, GIS, and location of disposal sites;
- Impacts of COVID-19-related waste streams;
- Role of MSWM in the CE.

Furthermore, given the limited international collaborations that South Africa has with other countries, there is a need to initiate and reinforce existing research linkages with other countries, thus involving a greater sharing of resources, capabilities, and experiences than is currently the case. Similarly, to stay current with the latest MSWM research, trends require further literature re-assessments from time to time to document new trends and identify research gaps.

5. Limitations of Study

The current study focused on peer review articles and book chapters that have been included in the Scopus database. It is possible that some important literature from conference papers and technical papers may have been missed. This has also been reported by other authors that conducted bibliometric analysis.

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