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A Scientometric Review of Chemical Management

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Chemical management is critical and has an enormous impact on our daily lives. Numerous advancements in chemical production have transformed management facets, most notably vis-à-vis safety, health, and environment. Thus, the scientometric review could depict and analyse publication trends in updating scientific datasets and knowledge in this field. This scientometric review is intended to scrutinise the progress, trends, and updates of publications concerning chemical management in the Scopus and Web of Science databases. The publication patterns and authors' keywords are among the scientometric parameters examined in this review. The obtained publication lists or metadata in this study were analysed using ScientoPy and VOSviewer software, which displayed the scientometric results graphically. The current study portrayed that the number of publications on chemical management has increased in both databases. The exploratory publications and research areas reveal that efforts to inspect chemical management cover miscellaneous topics and disciplines such as environmental science and ecology, engineering, and agriculture. The most related authors' keywords concerning chemical management are "Risk management", "Risk assessment", and "REACH". Researchers and practitioners may benefit from this scientometric review since it contains data, concepts, thoughts, and insights that can be employed to bolster their theories and practices in managing chemicals.

Keywords: Chemical management; Scientometric; Publication Trends; Scopus; Web of Science

I. INTRODUCTION

Chemicals are nearly ubiquitous and are adopted in virtually every aspect of life. A variety of chemicals are utilised daily for myriad purposes such as cooking, washing clothes, or cleaning kitchen equipment. Sterilisation of medical equipment is another concern for scientists, nurses, and physicians who use chemicals extensively (Chang *et al.*, 2020). Auto specialists also use chemicals to repair specialised parts, replace matched components, and perform assembly procedures (Doerre *et al.*, 2018). The inclusion of numerous chemicals in daily products can result in adverse effects. To that end, it is critical to recognise that individuals may be susceptible to these chemicals' possibly harmful consequences. Inadvertent advancements in science have meant that the quantity and variety of chemicals produced and used today have increased, negatively influencing the environment and life cycles (Gilbertson *et al.*, 2015). Laws and regulations have long governed chemical management; in 1972, the British Committee on Safety and Health at Work presented the United Kingdom Parliament with the Robens Report on occupational health and safety (Jonai, 2021). The existing legal regulations and guidance may be excessively ambiguous and open to interpretation.

Chemical's happenstance has caused many deaths, property damage, business interruption, and ecological damage each year. Besides, it is appalling that cancer, foetal malformations, respiratory, endocrine, cardiovascular, urinary system diseases, neurodevelopmental, and immune disorders are all possible outcomes of exposure to hazardous chemicals in the environment (Boyd & Genuis, 2008). It was an epiphany that some of the world's most horrendous

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chemical catastrophes have taken place at factories like the Bhopal disaster in India (Martins, 2021), Bright Sparklers in Malaysia (Ajmal *et al.*, 2021), and the Lapua Cartridge in Finland (Alahmad *et al.*, 2021). Also, other industries such as the defence, energy, mining, and education had a high rate of chemical mishaps (Abdullah & Aziz, 2020). Rather than being the result of risky procedures and behaviours, chemical-related disasters are also influenced by how chemicals are managed. It is undeniable that effective chemical management is essential in any industry and that further exploration is required.

Procurement, storage, use, and disposal of chemicals in a business are all part of chemical management (Syeda, 2020). Chemical management has evolved due to the increasing variety, use, and associated disasters. Consequently, the international community and governments emphasise the surfeit of preventing chemical health and environmental impacts (Vincenten *et al.*, 2020). Apart from self-regulation in Europe and the United States, all countries must adhere to pertinent United Nations recommendations and international chemical management standards. According to Jonai *et al.* (2021), chemical management is defined by self-regulation and compliance with global recommendations such as the International Organization for Standardization's 45001 and Control Banding for small and medium-sized businesses, the Montreal Protocol on Substances that Deplete the Ozone Layer, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, and the Stockholm Convention. Additionally, action plans such as the United Nations Sustainable Development Goals (SDGs) and the Globally Harmonized Systems (GHS) serve as examples.

Prioritising practical actions and allocating resources are critical components of a chemical safety plan and are necessary for chemical management (Coleman *et al.*, 2019). International chemical safety policies provide a framework for countries to implement evidence-based policy actions (Vincenten *et al.*, 2020). According to Vincenten *et al.* (2020), the United Nations 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs) commit to (i) substantially reduce deaths and illnesses from hazardous chemicals by 2030 (SDG 3.9), (ii) improve water quality by reducing pollution by 2030 (SDG 6.3), and (iii) achieve environmentally sound management of chemicals and all wastes throughout their life cycles to minimise the adversities (SDG 12.4).

The ultimate goal of virtuous chemical management is to manufacture and use chemicals for euphoria situations with the most negligible negative impact on human health and the environment as possible. Chemical control benefits the general public in numerous tangible ways and contributes to environmental protection and preservation. Thus, responsible chemical management entails preventing, remediation, and minimising chemical exposure (Syeda, 2020). Furthermore, it necessitates utilising the best scientific data available, internalising the costs of human and ecological health, and disclosing information about chemical releases and properties (OECD, 2020).

Global research expansion has become a critical task in ensuring the effectiveness of chemicals. However, scientometric reviews of chemical management research remain in short supply. Previous scholars have been enticed by scientometric agricultural waste management (He *et al.*, 2019), solar photovoltaic waste management (Oteng *et al.*, 2021), microalgae-based wastewater treatment (Li & Zhu, 2021), and agricultural pollution (Li *et al.*, 2022). In consequence, the primary objective of this study is to examine the scientific evolution of chemical management publications in the Scopus and Web of Science (WoS) databases. It will become a significant contribution to provide research output for readers, industry practitioners, policymakers, and future researchers; the plethora of chemical management practise that has been concentrated previously via this scientometric review.

II. DATA SOURCES AND METHODS

By merging metadata from two distinguished databases, explicitly Scopus and WoS, this study analyses the progress and present tendencies in chemical management using a scientometric method via Scientopy software. ScientoPy is the software platform that will handle essential publications data such as keywords, countries, and institutions. ScientoPy is a Python-based scientometric analysis programme that is free and open-source, and it has the potential to reduce bias in individual publications (Ruiz-Rosero *et al.*, 2017).

Scientometric, bibliometric, informetric, webometric, and cybermetric; are all metrics research with slightly distinct concepts and customs. The terms allude to the disciplines' dynamics as manifested in their literary productions. For example, scientometrics is defined as a quantitative technique to analyse the evolution of science (Su & Lee, 2010). It is used to assess the impact of research, better understand the citation process, and map the structure and evolution of knowledge using large-scale academic datasets (Zhong *et al.*, 2019). When doing systematic reviews, undertaking a scientometric analysis can provide important information, mainly when relevant and up-to-date systematic reviews are not readily available (Chen & Song, 2019).

A. Data Retrieval and Initial Data Analysis

On February 18, 2022, the bibliographic data in this study was retrieved using the Scopus and WoS search engine. These databases were favoured and ethereal in the academic circle because they contain reliable, high-quality research sources, original ideas, discoveries, and new-fangled knowledge. The data retrieval process began with recognising precise keywords, pertinent information, and the analysis's specific objective. The metadata for this study was assembled using the keywords "chemical management" OR "management of chemical" OR "chemical* manag*" OR "manag* of chemical*" based on the article title. Truncation or stemming was employed in the search string to extend the search, including alternative word ends and spellings.

The metadata obtained during the retrieval process had returned 758 results from both databases. The commencement year of publication is collected in ScientoPy's default configuration, which is 1990, and the retrieved data is composed until February 18, 2022. Nonetheless, this study pre-processes the attained metadata. ScientoPy handles data at this level according to the following document types: (i) conference paper, (ii) article, (iii) review, and (iv) proceeding paper (Ruiz-Rosero *et al.*, 2017). Other document categories, such as books, book series, and letters, were omitted from the databases. As a result, there are 173 documents that have been left out. Furthermore, ScientoPy normalises the author's name during the pre-processing stage by replacing it with a semicolon and removing dots, commas, and special characters. Similarly, duplicate samples with the same title and authors were removed. During this stage, 137 duplicate metadata records were discovered and had been deleted.

As shown in Figure 1, the pre-processing graph displays the whole set of imported documents for each database, as well as the deleted duplicate records. According to Figure 1, the ScientoPy pre-processing script prioritises Scopus documents above WoS documents; after duplicate removal, more papers were in the Scopus rather than WoS. Following data reconciliation, this study examined 448 lists of publications from both databases, specifically 262 publications from Scopus and 186 publications from WoS, after removing 135 duplicates (34%) from Scopus and two (1%) from WoS. The scientometric analysis in this study is justified and warranted with the number of publications had exceeded 300 (Donthu *et al.*, 2021).

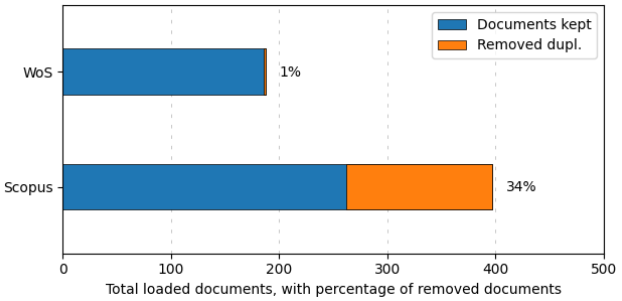

Figure 1. Pre-processing of metadata from Scopus and WoS databases

III. RESULTS AND DISCUSSION

A. Publication Output and Research Area

The frequency of publications in any study topic is essential in determining the escalation and research progress. Figure 2 depicts the progression of chemical management publications in Scopus and WoS databases with exponential growth. In 2002, the cumulative number of publications in the Scopus database surpassed WoS. Nonetheless, between 2020 and 2021, the ratio of publications in the WoS climbed by 12.5% compared to Scopus (8.5%). Chemical management research has shown that even though chemicals can have a significant impact on people's health and safety, their properties, and the environment, they can also have a considerable effect on the economy and society, as well as people's lives and their environment (Wang *et al.*, 2018). Hence, due to communities and the economy's rapid

advancement, the quality criteria for chemical production need to be improved, which means that sound chemical management will directly influence industrial output. Therefore, the study of chemical management should be long-drawn-out. It is noteworthy that governments and non-governmental organisations should provide research funding and financial assistance to scholars to encourage additional research on chemical management, especially towards environmental sustainability.

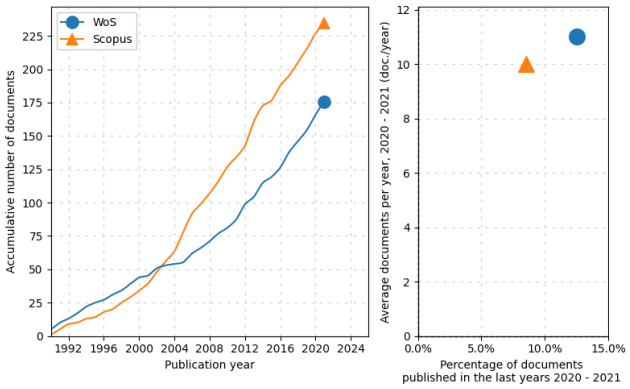

Figure 2. Publication output of chemical management in Scopus and WoS

Figure 3 portrays a bar trend graph with 20 subject areas in chemical management, with Environmental Sciences and Ecology taking first place with 43 publications. Engineering is ranked second (42 publications), and Agriculture is ranked third (27 publications). By observing the current trend in the last two years (2020 and 2021), chemical management has attracted 24% of the research area in Chemistry and Public, Environmental and Occupational Health. Other research areas that have published papers with 10% and more in 2020 and 2021 include Engineering (10%), Plant Sciences (13%), and Agriculture (18%).

According to these findings, chemical management is inextricably linked to public health, occupational safety, environment, chemistry, and agriculture. It is crucial because chemical management is an integral aspect of managing safety, health, and the environment. A plausible reason is that chemical management, similar to that used in hospital waste management, should include waste storage and treatment before disposal, thereby preventing pollution and requiring the government to build a monitoring system (Abidar *et al.*, 2020).

Chemical and waste management are critical components of achieving the Sustainable Development Goals (SDGs) (Syeda, 2020). Circuitously, this reveals that research on chemical management pertinent to environmental issues is accomplished to ensure that efficient and effective chemical management could protect human life from the hazardous repercussions of poorly managed chemicals. It is comparable in engineering because it also deals with unsafe chemical management. Hazardous chemicals are substances employed in various engineering industries for manufacturing, analytical, and research purposes. Any unforeseeable incidents that lead to harm or property damage in the engineering sector might occur if chemicals are mismanaged. Thus, the engineering discipline is also actively involved in publishing articles on chemical management for their references and guides.

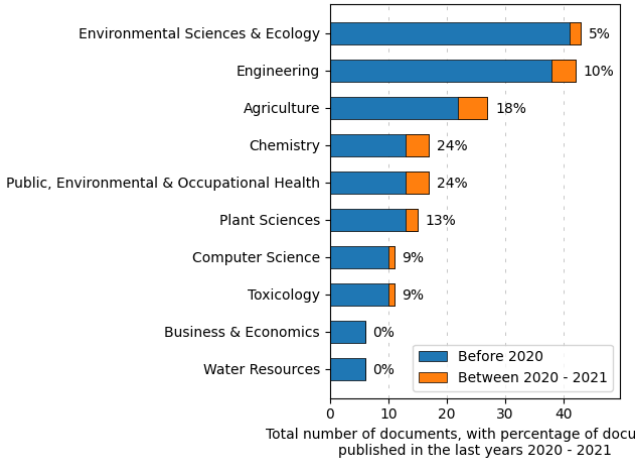

Figure 3. A bar trend graph of 20 research areas

B. Descriptive Analysis of Publication Trajectories

This study begins with a descriptive analysis of source titles. Source titles refer to a journal article, a conference proceeding, or a book. For this classification, Figure 4 depicts a cloud diagram containing 20 sources that have published articles on chemical management, noting that the groundwork with the most documents is issued by Sustainable Development and the Importance of Chemicals Management in the 21st Century with a total of nine articles. The second position is Chemical and Engineering News, with six publications. And it is trailed by Chemicals, Environment, Health: A Global Management Perspective, Chemical

Engineering Transactions, Environmental Sciences Europe, Environmental Science and Pollution Research, Planta Daninha, and Science of The Total Environment, with a total of five articles and had become the third-ranked. As evidenced by the list of publications, there will be a sizeable impact on academic life as a means of obtaining or publishing articles on chemical management. For instance, publications in Chemical and Engineering News; is a weekly news magazine published by the American Chemical Society that covers professional and technical chemical news and analysis. As a result, this source contributes reliable and critical information to researchers' work pertinent to chemical management that the scholars would favour. In addition, source titles used to publish papers and references cited can serve as a valid indicator for research institutions to see how effectively their researchers are using the subscribed journals (Ramamoorthi & Jeyshankar, 2016).

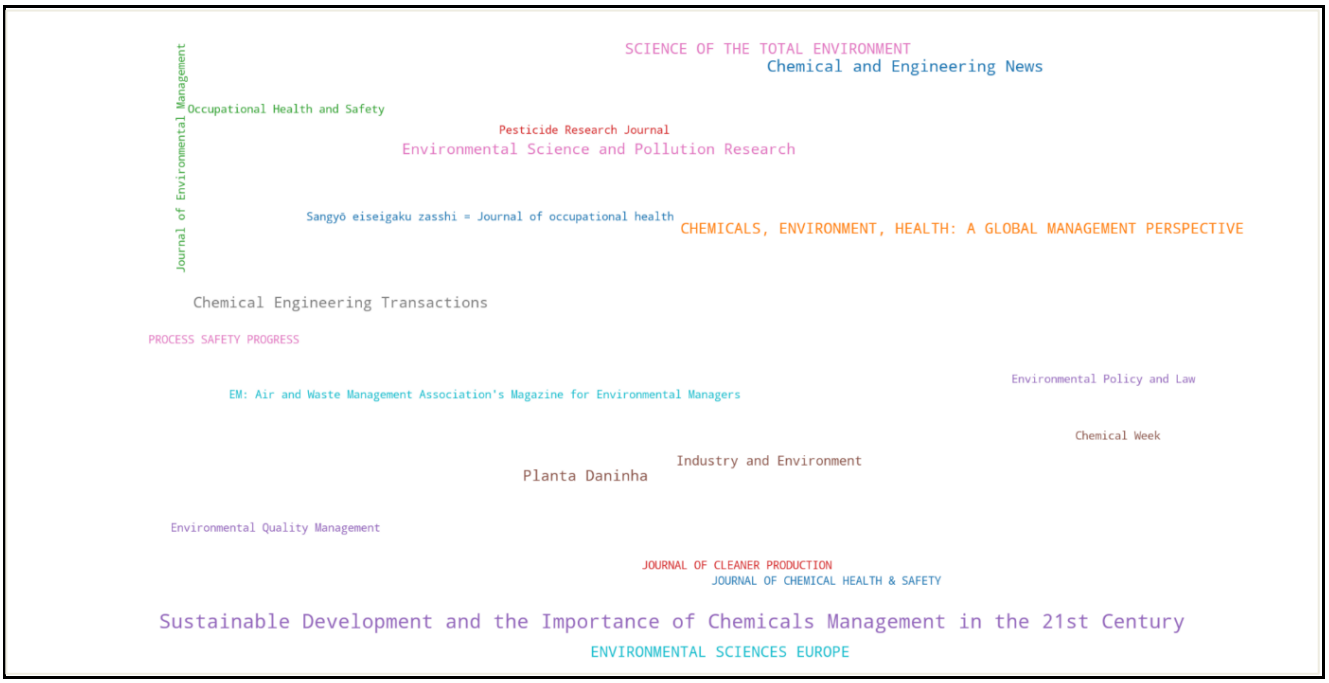

Figure 4. A cloud diagram of 20 source titles

Table 1. The top ten productive countries

Position	Country	Total	AGR	ADY	PDLY	h-index
1	United States	89	-1	1	2.2	14
2	Brazil	26	0.5	3	23.1	9
	China	26	1	4	30.8	5
3	Sweden	21	-1.5	1	9.5	8
4	Japan	20	2	2	20	3
5	Germany	19	-1.5	1	10.5	8
	India	19	0.5	2	21.1	3
	Italy	19	0	2	21.1	8
6	United Kingdom	18	-0.5	0	0	7
7	Canada	16	0	0	0	6

The second descriptive category examined in this study is country. Table 1 lists the top ten countries with the most articles published between 1990 and 2021. The table consists of information based on position and country ranking, total publications, annual growth rate (AGR), average document per year (ADY), percentage documents on the last two years (PDLY) and h-index. The United States posits as the most active country in publishing research on chemical

management, with 89 publications and an h-index is 14. Chemical management is thus evidently critical in the United States. The fact is that, following decades of debate, the United States Congress enacted a significant revision to the 1976 Toxic Substances Control Act (TSCA), the federal regulatory law governing industrial chemicals in the United States (Botos *et al.*, 2019). Moreover, the American Chemical Society's Strategic Plan identifies safety as a fundamental value. To carry out this value, the Committee on Chemical Safety (CCS) planned and hosted strategic ACS Safety Summits in 2018 and 2019 to discuss the opportunities and challenges presented by this value (Stuart, 2019).

With 26 publications, Brazil has placed its position in the second rank. Yet, the PDLY, which is depicting 2020 to 2021, reveals that Brazil achieved 23.1% above the United States. This happened as Brazil is the eighth largest producer of chemicals globally, but it has yet to develop a comprehensive regulation governing the safe handling of industrial chemicals (Mourão & Sales, 2020). Numerous attempts have been made previously, but none have resulted in the effective implementation of specific legislation on the subject. The shared position country with Brazil is China. Chemical management in China is frequently centred on new chemicals (i.e., newly manufactured or imported) and trace organics that are used or can enter the environment as a natural by-product of our daily lives (Zhu *et al.*, 2016).

In this study, Sweden is positioned in third-ranked with 21 publications on chemical management. In Sweden, an estimated 62,659 tonnes of chemicals were emitted from preparations, prescription pharmaceuticals, and textile-associated chemicals into the wastewater stream (Gustavsson *et al.*, 2022). Additional research can guide environmental monitoring and inform the implementation of chemical management strategies whenever the per capita emission to wastewater is a concern in Sweden.

Meanwhile, publications on chemical management have been issued by 59 institutions. The ten institutions with the most articles published are depicted in Figure 5. There are universities and professional institutions that make up the organisation. Deltares is a non-profit institute in the Netherlands that conducts applied research in water and subsurface hydrology. IVL Swedish Environmental Research Institute has a diverse range of environmental responsibilities. Radboud University is a public research university in the Dutch city of Nijmegen. The University of Sao Paulo is a public university in Sao Paulo, Brazil. It is the country's most prestigious and largest public university.

The most cited paper (188 citations) published in 2017 by Deltares with other co-authors is entitled "Towards the review of the European Union Water Framework Directive: Recommendations for more efficient assessment and management of chemical contamination in European surface water resources". Additionally, researchers from the IVL Swedish Environmental Research Institute and Radboud University contributed to this article. The article highlighted the following three points about chemical management: enhance monitoring and strengthen comprehensive prioritisation of toxic pollutants, promote consistent water pollution assessment, and promote solution-oriented chemical management in the water cycle.

The most cited paper issued by the University of Sao Paulo was entitled "Soil chemical management drives structural degradation of Oxisols under a no-till cropping system". This paper studied the relationship between chemical management and structural degradation in Oxisols cultivated under no-till (NT) at three sites in southern Brazil. It was discovered that structural degradation of Oxisols grown under NT, which was observed primarily in the subsurface layer, was exacerbated by the accumulation of amendments and fertilisers in the surface soil and low levels of organic matter, particularly in the subsurface layer.

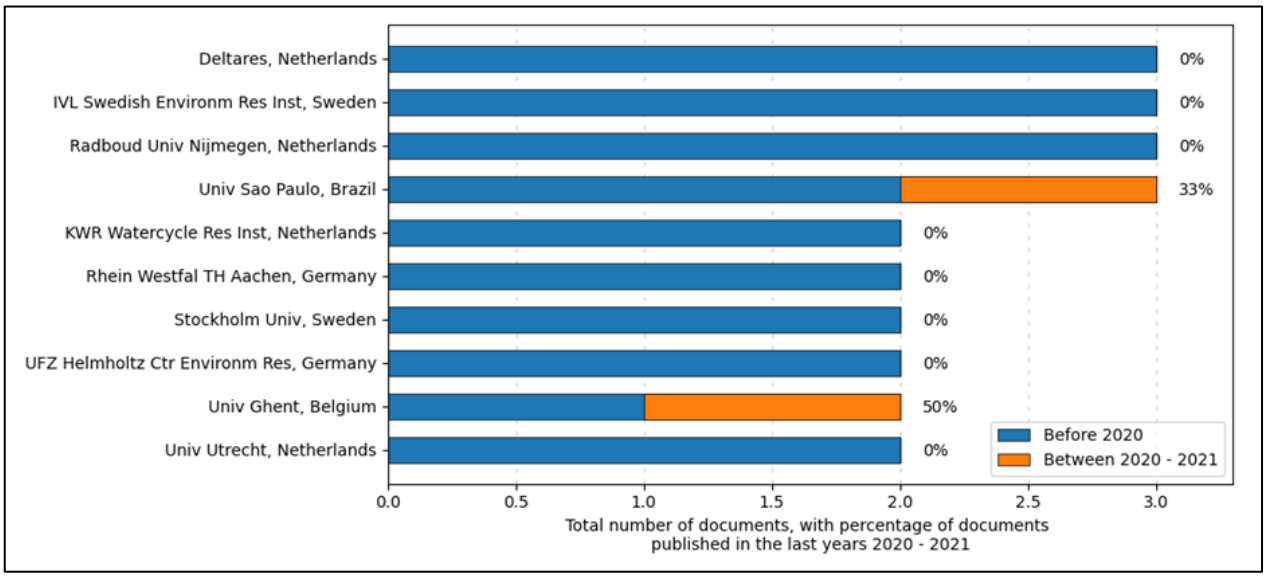

Figure 5. A bar trend graph of 10 institutions with at least two publications

C. Analysis of the Author's Keywords

The author's keywords define the article's field, subfield, topic, and research issue in any publication. In addition, other researchers may conduct a topic search to locate papers using precise keywords. Most electronic search engines, databases, and journal websites use author keywords to identify and display relevant documents to attentive readers. This study analysed the top ten author keywords based on their co-occurrence in previous studies. Figure 6 depicts the total number of publications for the top ten authors' keywords, along with the percentage published over the last two years (2020 to 2021).

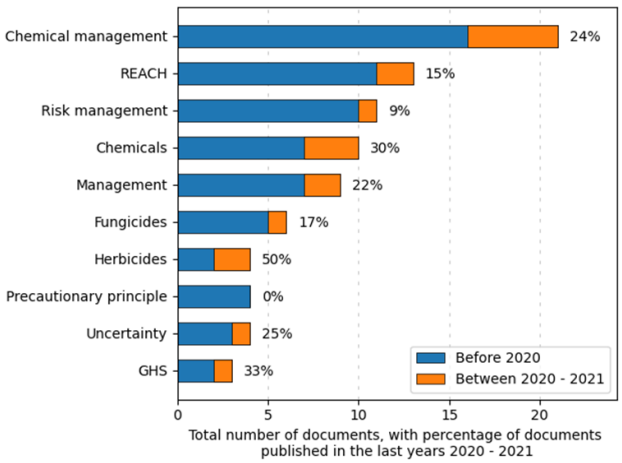

Figure 6. A bar trend graph of authors' keywords

This study's top three keywords were "Chemical management" (21 publications), "REACH" (13 publications), and "Risk management" (11 publications). The metadata processing preceded these broad terms directly related to the subject; following that, significant keywords are available to assist readers and future researchers in determining the suitability of the keywords for conducting document analysis. In this study, the most trending authors' keywords from 2020 to 2021 with 25% and above of the total publications were uncertainty (25%), chemicals (30%), GHS (33%), and herbicides (50%).

Still, this study used cluster mapping to determine the co-occurrence of authors' keywords to identify themes or topics relevant to chemical management. The dataset (a combination of Scopus and WoS metadata) was pre-processed with ScientoPy before generating a network map with the VOSviewer. The frequency of keywords occurring in VOSviewer was proportional to the rectangle's size. The lines represented the nexus among keywords. The link strength of the nexus depended on the lines' thickness, which indicates the degree of co-occurrence. Figure 7 illustrates the authors' keywords in a network visualisation diagram, highlighting their links to other keywords through the use of colour, node size, text size, and the thickness of connecting lines. The minimum number of keyword occurrences in this analysis was 5, and out of 747 keywords, 6 met this threshold.

Figure 7 shows that the keywords "Risk management", "Risk assessment", "Chemical management", and "REACH"

were all found in the same cluster (blue rectangle). "Chemical" and "management" are the other groups denoted by the green cluster. By analysing Figures 6 and 7, it was clear that the keywords were essential and linked to the significant nexus. This information could indicate that previous research on chemical management focused on those keywords. For example, "REACH" is related to "risk management." REACH is an abbreviation for the European Union's Registration, Evaluation, Authorisation, and Restriction of Chemicals. In practice, the European framework for the concepts of waste, by-product, and end-of-waste status creates significant (legal) uncertainty, particularly concerning REACH, the European Union's most important chemical risk management regulation (Bodar *et al.*, 2018). Humans and the environment are exposed to minute amounts of hundreds of different chemicals daily through food, consumer products, air, and water. In order to reduce the risk that these chemicals pose to public and environmental health, their introduction into the market must be strictly regulated, requiring a risk assessment that considers the impact on both ecological and human health (Bopp *et al.*, 2019). From this perspective, we should be absolutely certain that those chemicals must be adequately controlled regardless of whether or not they are safe to use. In effect, proper risk management needs to be made mandatory.

From 2020 to 2021, "GHS" became one of the trending keywords in this study. GHS is an acronym of Globally Harmonized System of Classification and Labelling of Chemicals. GHS is one of the global initiatives to improve chemical hazard communication worldwide. The goal is to make it easier not only to trade chemicals across national borders but also to make it more accessible to use chemicals safely. There have been problems with the adoption of different versions of the GHS document, the adoption of other building blocks, the creation of a list of classified chemicals, the impact of the confidential business information on the supply chain, and the definition of GHS implementation all over the world (Ta, 2021). Thus, GHS is gaining popularity, most likely due to the necessity for in-depth studies to address the concerns and problems associated with GHS. This is critical for enhancing the overall quality of chemical management.

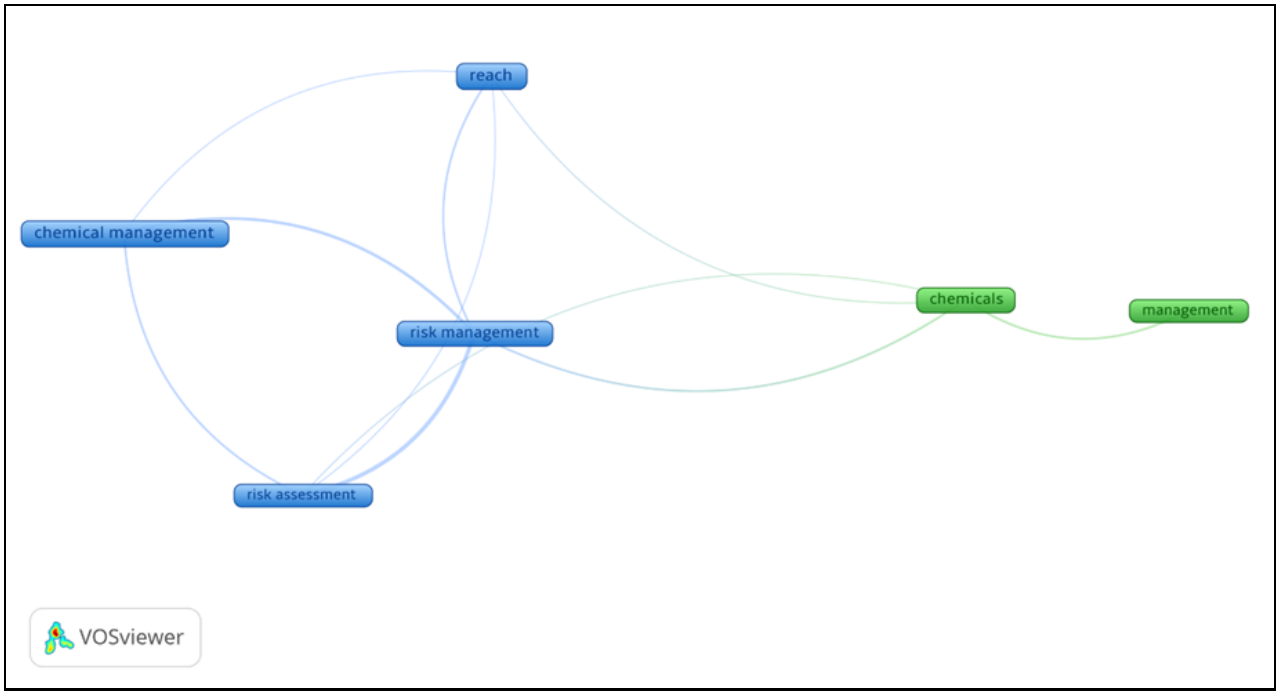

Figure 7. A network visualisation diagram of the co-occurrence of authors' keywords

IV. CONCLUSION

A scientometric approach is a valuable technique for mapping published research on chemical management. Additionally, significant concepts from the literature were acknowledged, as was an understanding of how the field's research trends evolve and interact. This study demonstrated that publications on chemical management in the Scopus and WoS databases grew exponentially. Sustainable Development and the Importance of Chemicals Management in the 21st Century has become the most active source title that published papers on chemical management.

The United States was found to be the most active country in this study, with 89 publications on chemical management research. Chemical management is critical in the United States, as evidenced by the fact that it has piqued the interest of American researchers. Deltares, the IVL Swedish Environmental Research Institute, Radboud University, and the University of Sao Paulo are among the prestigious institutions that have published the most papers on chemical management research.

The current work demonstrates a clear trend in the development of chemical management, with the trending topics in the last two years (2020 to 2021) being "uncertainty", "chemicals", "GHS", and "herbicides", as demonstrated by scientometric analysis using ScientoPy. Additionally, after analysing the term chemical management with VOSviewer, it can be shown that the term chemical management is associated with "Risk management", "Risk assessment," and "REACH". These keywords are critical for future researchers to examine in greater detail to comprehend their relationship through scoping reviews or systematic literature reviews.

This study is merely a starting point that could be expanded upon with a more in-depth examination of thematic content. The findings of this study may provide a theoretical perspective on the subject, a map of the current state-of-the-art, and highlight potential gaps in scientific research. A significant aspect of this scientific analysis is that it may serve as a springboard for future and more robust research on chemical management, specifically procurement, storage, use, and disposal. It would also be interesting if future researchers could combine computer technology, the Internet of Things (IoT) and chemical management to create a chemical management system that could track information from purchase to disposal. Such symbiotic systems are essential for easily tracking chemicals and assisting users in managing chemical stocks and usage. To conclude, researchers and practitioners may benefit from this scientometric review's study of metadata, concepts, thoughts, and insights to reinforce their theories and practise in chemical management.

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