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ANALYSIS OF WASTEWATER TREATMENT AND ENVIRONMENTAL POLICY DEVELOPMENT: BIBLIOMETRICS AND VISUALIZATION

Washilla Audia[1], Aldri Frinaldi[1], Dasman Lanin[1], Rembrandt[1], Genius Umar[1], Yulkifli[2], Nurhasan Syah[3], Alwi Nofriandi[1], Cici Aprilliani[1,4], Kiki Amelia[1], Fanny Yuliana Batubara[1], Rindi Genesa Hatika[1], Cory Febrina[1,5], Abdi Iswahyudi Yasril[1,4], Juli Hendrita[1]

[1]Doctoral Program of Environmental Science, Postgraduate Program, Universitas Negeri Padang, 25132, Air Tawar, Padang, Indonesia
[2]Department of Physics, Faculty of Natural Science and Mathematics, Universitas Negeri Padang, 25132, Air Tawar, Padang, Indonesia
[3]Environmental Science Study Program, Postgraduate School, Universitas Negeri Padang, 25132, Air Tawar, Padang, Indonesia.
[4]Public Health Study Program, Universitas Fort de Kock, 26111, Bukittinggi, Indonesia.
[5]Faculty of Nursing, Universitas Fort de Kock, 26111, Bukittinggi, Indonesia.

*E–mail: washillaaudia@student.unp.ac.id

ABSTRACT

The global water pollution crisis exacerbated by anthropogenic activities demands effective integration between science and policy. The objective of this study is to map the intellectual landscape and trends in research development at the intersection of wastewater treatment and environmental policy development through bibliometric analysis and visualization to identify gaps between scientific progress and policy adoption.This study conducted a comprehensive bibliometric analysis of 285 publications to map the intellectual landscape and evolutionary trajectory at the interface of liquid waste contamination and environmental policy. Findings reveal an exponential acceleration of research since 2014, with 75.78% of publications concentrated in the last decade, reflecting increasing global urgency. China dominates as the research epicenter with the highest productivity (56 publications), the greatest citation impact (1,914 citations), and a role as a key collaboration link. Thematic analysis confirms the consolidation of this field around the core concepts of “environmental policy” (228 occurrences) and “wastewater treatment” (215 occurrences), marking a paradigm shift from technocratic approaches toward holistic policy integration. However, the polarization of international collaboration into 10 cohesive clusters indicates a fragmentation of global discourse. Critically, this study identifies an alarming disparity between rapid scientific progress and lagging policy adoption capacity, highlighting the urgent need for adaptive policy frameworks and transdisciplinary collaboration mechanisms to bridge the implementation gap and respond more effectively to emerging contaminants.

Keywords: wastewater treatment, environmental policy, bibliometrics, origin, VOSviewer

INTRODUCTION

Since then, anthropogenic pollution spills from households, industries and agricultural waste have been a global water crisis that there is no way out of. According to the 2023 report issued by International Union for Conservation of Nature (IUCN), approximately 35% species of freshwater fish in Indonesia are threatened with extinction due river polluted. More than 60% of rivers in Indonesia are also contaminated, the Ministry of Environment and Forestry reported it is clearly not water quality. Untreated waste water discharge, dumps a full spectrum of pollutants into aquatic environment including toxic

*Corresponding Author: washillaaudia@student.unp.ac.id

heavy metals, pathogens and nutrients alongside emerging contaminants such as Pharmaceutical and Personal Care Products (PPCPs) among them microplastics. This web of poisons is not just decimating biodiversity and soil vitality, it also poses the gravest threat to human security by undermining access to clean water a right that has been recognized internationally as a basic human right upheld by United Nations treaties. Heavy metals are the primary and most pervasive groups of pollutants that unleash life-threatening mechanisms on a broad scale with reference to bioaccumulation, influence food chain contamination leading up to soil health deterioration which results in hampering agricultural productivity along with increase major concern for microbiological diversification (Lavanya et al., 2024; Yurnalisdel, 2022). The magnitude and structure of this problem requires not just a detailed understanding of the scientific evolution behind many contaminants, but also (and more critically) recognition in their environmental policy settings by effective operationalisation.

The contaminants found in liquid waste become more complex, so there must be more sophisticated policy responses. Regulators using traditional command-and-control policies usually cannot keep pace with innovation and science. Kotchen et al. (2020) discuss how, in response, policies have shifted to adaptive management, information disclosure, and market-based instruments. These policies do not adequately represent the complex interaction of science measuring risk and exposure, and the policy constructing governance from that science. Such mapping is the base for more complex science policy interaction to achieve rational governance that responds to water safety.

While previous literature reviews have focused on individual aspects of waste treatment technology or environmental policy, this has resulted in an incomplete understanding of the synergistic potential of science and governance (Crini & Lichtfouse, 2019; Schwarzenbach et al., 2010). This gap in literature requires an integrative and datacentric approach, which is where bibliometric analyses come in handy. Bibliometrics is the study of the quantitative assessment of publications, and through the analysis of metadata and citations, it is able to indicate the social structure, conceptual framework, and the direction of the research field (Donthu et al., 2021).

Bibliometric analysis involves using techniques to track scientific communications, and provides solid means of outlining the structure of a domain of study, establishing its publications and their patterns, determining its authors, and their publication constituents, and identifying focal themes (Barth & Marx, 2017; Cui et al., 2024; Jumilah et al., 2025a; Khan et al., 2023; Putera et al., 2022; Shao et al., 2022; M. Tang et al., 2023; Z. Tang et al., 2024; Wang et al., 2022; Wen et al., 2020; Yu et al., 2023). With the help of instruments like VOSviewer, bibliometric analysis converts abstract data into a matrices that show the positioning of key ideas, the developments of a domain, and its current position in the fields of study (van Eck & Waltman, 2017).

In METZE (2020) stakeholders can see new directions in research and new policies through the interpretable frameworks enabled by visualization techniques which convert complex bibliometric data. It is also the case that many bibliometric studies solely focus on the technological dimension. However, thorough bibliometric studies that also consider the evolution of policies relating to the environment and their policies are extremely few in

*Corresponding Author: washillaaudia@student.unp.ac.id

number. This is probably the most important reason why a thorough study on the integration of scientific and policy elements has become a necessity.

Recent studies have shown a wide range of pollutants in the environment, especially contaminants in the water. These include contaminants in mangrove sediments such as iron, manganese, nickel, chromium, copper, cobalt, and arsenic (Thanh-Nho et al., 2019) and also new pollutants such as SARS-CoV-2 RNA in wastewater and surface water (Mancuso et al., 2021). New methods are being introduced to remove contaminants, such as the use of waste polyacrylonitrile fiber-based composites in the extraction of uranyl from uranium carbonate solutions (Liu et al., 2022). However, even scientific solutions have their limitations which are due to the absence of effective frameworks and policies in the sphere of environmental governance (Nega et al., 2024; B. Zhang et al., 2023).

For instance, urban environmental legislation shapes Corporations environmental performance due to incoporating regulatory controls on emissions and waste disposal (B. Zhang et al., 2023). The influence of legislation has been highlighted for the flexible management of different waste types =solid (Anshari, 2020; Cui et al., 2024; Dragomir & Dumitru, 2024a; Khan et al., 2023; Meena et al., 2023; Rafiq et al., 2023a; Shi et al., 2021; Thanopoulos et al., 2020) and plastic (Jirapornvaree et al., 2023; Rai et al., 2023) to dangerous and consruction waste.

What makes this research original is how it combines several different disciplines together. In this case we are conducting a science-policy interface via bibliometric analysis and visualization which will help us investigate and document the progression of several fields at the same time, and how they relate to one another. In this particular case, we'll look at the science of liquid waste and how it relates to the critical environment policy of liquid waste, as well as the dissolutions and mechanisms that impede the scientific policy gap. This will result in a complete map that aligns a research strategy with the policy gap and, in turn, improves the environmental governance policy.

This article aims to conduct a importation as well as a detailed analysis of the existing public policy developing literature in the area of liquid waste management. In order to conduct the analysis as well as identify the main topics and knowledge deficiencies in the public policy developing literature, the imported analysis will delve into the reconfiguring knowledge in the public policy developing literature within the waste management domain. The main objectives of the analysis include the mapping of the knowledge in the area of public policy developing literature in the waste management domain, the determination of the principal knowledge reconfigurations, the identification of the researcher and institutions' knowledge co-creation networks, the investigation and the knowledge co-creation pathways, and the analysis of the knowledge co-creation networks. The analysis will lead to the identification of a number of knowledge and the implementation gaps which can be of great use to the people working in practices and the public policy makers in the area of liquid waste pollution management. Plus, the analysis will help in the development of various strategies and innovative ideas to address the stream of problems which will eventually lead in the attaining of the efficient and the sustainable management of liquid waste.

*Corresponding Author: washillaaudia@student.unp.ac.id

MATERIALS AND METHODS

2.1 Data Collection and Extraction

The data in this study were gathered via a systematic review conducted in the Scopus database on September 17, 2025, so that data collection in the study could be conducted in a systematic manner that allows for consistency and reproducibility. The following search strategy was implemented: TS = ("wastewater treatment") AND TS = ("environmental policy") with a custom year range of 1982–2025. This ensures coverage of the documents that span the years where there was a global increase in environmental awareness, and there is a corresponding increase in the global literature pertaining to the environment. The documents were also filtered to include only original, empirical, primary research articles in the English language. The search strategy yielded 285 documents, which were then appropriated to each of the two researchers to determine the credentials of the documents with respect to the suitability of the abstract and the complete text. For the purpose of systematically reducing bias and increasing reliability, the two researchers each chose a third, independent, arbitrating researcher to act as a judge where there were discrepancies within the selections. All documents where there was consensus were included in the metaanalysis. A flow chart of the data collection strategy is included as Fig 1.

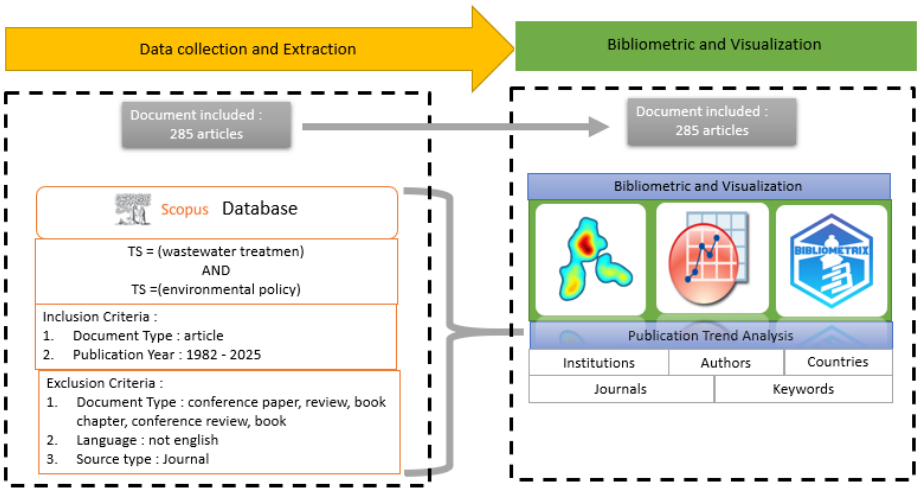

Fig 1. Data Filtering Flowchart and Bibliometrix Analysis Procedure

2.2 Bibliometric Analysis and Visualization

Different Applications were employed for different functions that were necessary for this study, from extracting, processing, and visualizing metadata for various study fields and their specialties, establishing VOSviewer (v.1.6.20), Microsoft Excel (v.2019), and Origin (v.9E5) and Bibliometrix (v.2019) for bibliometric analysis, Origin provided for the final graphical and statistic visualization for the study results. The software bibliometrix were utilized for analysis of distribution by years in the study, productivity of authors, co-authorship and collaboration of institutions, analysis of citations and metrics of impacts in the study like H-index, and analysis of networks and citation of bibliometric data. Then,

*Corresponding Author: washillaaudia@student.unp.ac.id

VOSviewer was used to analyze and create different maps for co-occurrence of different keywords; thematic, and were mapped to specific researchers or institutions based on the collaboration and their proximity. The tools used significantly improved visualization of results and data, and ultimately analysis of the study was provided in a more detailed manner to show where the data differed and results improved.

RESULT AND DISCUSSION

3.1 Publication Trend Analysis

The body of this study included an analysis of 285 articles from 1982-2025. From this body of work, it was determined from data analysis that from 73 contributing countries and 1,216 authors, 34, from 134 publications, and 2,460 references, and 31.97 averages of citations per document, that the research has broad prospects and impact to academia. Publication trends indicate that from 2014 fantasy to 2025 smut there was a phenomenal transformational change, indicating an initiation phase of a rapid progressive growth that characterizes this collection of work. Figures indicate the number of publications and the citations pertaining to the research of wastewater and the corresponding policy spanning 1982 to 2025. In the period from 2014 to 2025, the research output of this collection/ body of work averages 6.67 publications per year illustrating a rapid growth smut 2021 showing a peak of 35 articles publications and 2023 showing 25 publications. The fact that 216 articles, which represents 75.78% of the total looks number of publications over this period of time, crystallizes to indicate to the informed reader the sudden increase of publications smut the high relevance of this newly congruous body of work to post graduate studies, and indicates the maturity of postgraduate studies in this topic. The relevance to postgraduate studies is noted in Fig. 2.

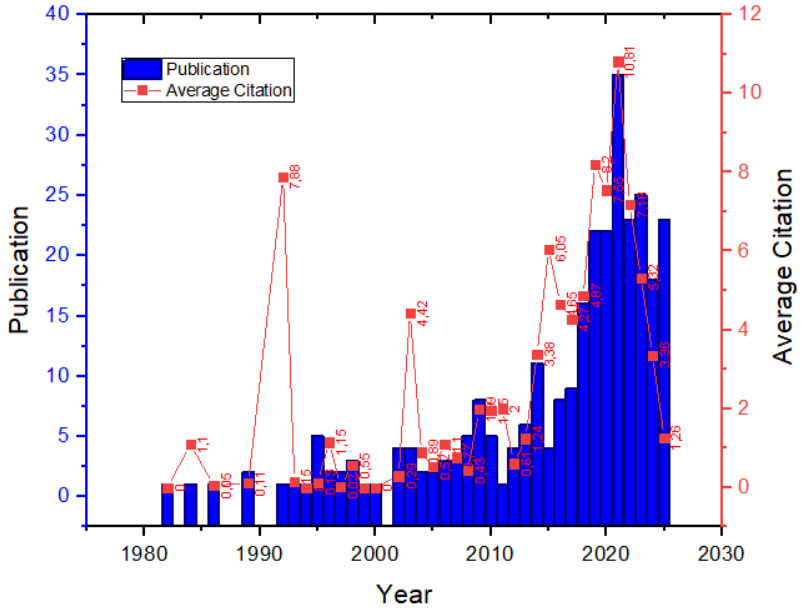

Fig 2. Annual Publications and Citations on Wastewater Contamination Analysis and Environmental Policy Development from 1982 to 2025

*Corresponding Author: washillaaudia@student.unp.ac.id

The citation metrics show further advanced positive developmental trends and increasing levels of research quality and influence in both metrics within the body of work. In the year of 2021 alone, average citations reached 10.81, while the article “Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development” published in that year within the Elsevier journal Chemosphere reached 954 citations, averaging 190.80 citations per year. These impacts metrics not only further prove the more than considerable scientific attention the work has achieved, but also believe and support the research's focus on emerging issues that has broad impact within the integration of liquid waste management and environmental policy. The ecometrics in complementary growth in both the productive and impact metrics confirms this area of research has entered a highly productive and focused phase of development within the core of environmental science and public policy.

To affirm the originality of this study, a comparative analysis of the existing bibliometric research maps was undertaken. The Publish or Perish application was utilized to conduct a systematic search of the literature using the desired keywords “wastewater,” “environmental policy,” and “bibliometrics” from the Scopus database highlighted in Fig 3.

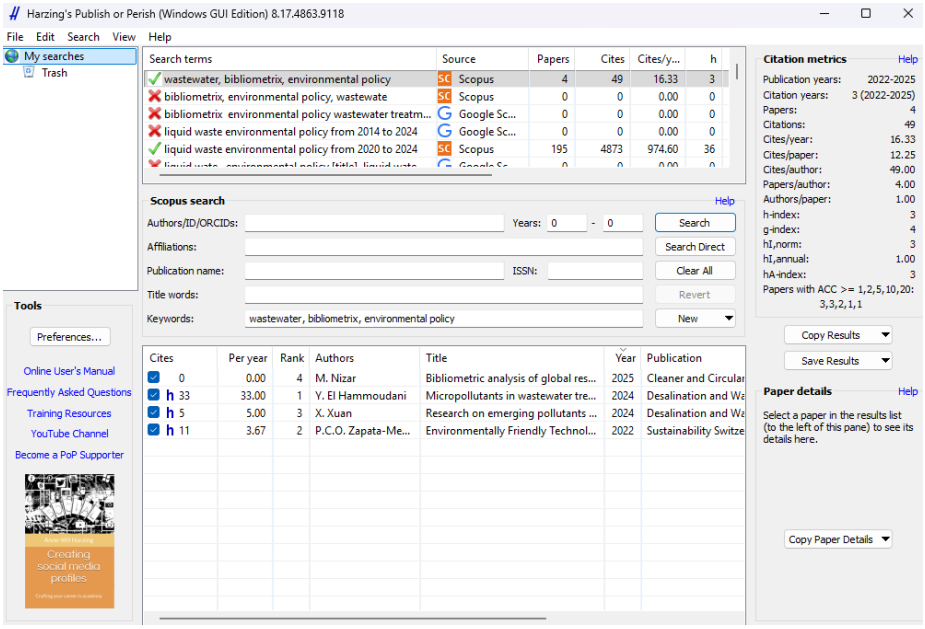

Fig 3. Results of Publishing or Parishing for Research Novelty

From the analysis conducted, there were exactly four review articles that had the same mapping scope as shown in figure 3. These four articles have been subjected to in-depth analysis as regards to their methodology, scope of analysis, and major findings, and this has been placed in a comparative manner in table 1. These findings irrefutably confirm the existence of a major research gap. These findings also affirm and justify the contribution of this study towards addressing the gap in analysis in the area of environmental policy integration and waste water contamination through a thorough bibliometric approach.

*Corresponding Author: washillaaudia@student.unp.ac.id

Table 1. Analysis of Research Novelty

Year	Title	Application (software) Analysis	Database	Analysis Performed
2025	Bibliometric analysis of global research on organic waste enzymes for plastic biodegradation: Trends, microbial roles, and process optimization	VOSviewer (keyword network visualization & collaboration), Bibliometrix/Biblioshiny (trend & statistical analysis), Excel (data cleaning).	Scopus, Web of Science (WoS), and Google Scholar.	Temporal Trends (publication growth), Keyword Analysis (co-occurrence for identifying dominant and emerging themes), Collaboration Analysis (international networks), and Interdisciplinary Analysis (linkages between biotechnology, environmental engineering, and policy) (Nizar et al., 2025a).
2024	Micropollutants in wastewater treatment plants: A bibliometric - bibliographic study	Bibliometrix (in R) for core analysis, Biblioshiny for interface & visualization, VOSviewer for network visualization.	Scopus	Mapping Research Interests, Remediation Strategy Progress (processing methods), and Standard Bibliometric Analysis (trends, keywords, collaboration) to understand the evolution of this field and its implications for technological innovation and global policy reform (El Hammoudani et al., 2024).
2024	Research on emerging pollutants in wastewater: Bibliometric analysis	Bibliometrix package (in R) for bibliometric analysis	Web of Science Core Collection	Publication characteristics, country contributions (China, India, Spain), highly cited literature (pharmaceuticals & personal care products), policies, detection methods (GC/LC), and treatment technologies (oxidation, constructed

*Corresponding Author: washillaaudia@student.unp.ac.id

				wetlands, enzymatic) (Xuan et al., 2024).
2022	Environmentally Friendly Technologies for Wastewater Treatment in Food Processing Plants: A Bibliometric Analysis	VOSviewer version 1.5.18 and Bibliometrix version 4.0.0	Scopus	The evolution of environmentally friendly technology for wastewater treatment in food processing plants (Zapata-Mendoza et al., 2022).
2025	Bibliometrics and Visualization of Analysis Wastewater Contamination and Environmental Policy Development (Penelitian saat ini)	Bibliometrix, VOSviewer (version 1.6.20), Microsoft Office Excel (version 2019), and Origin (version 9E5)	Scopus	Publication trend analysis, country/region analysis, institutional analysis, author analysis, journal analysis and frequently cited journals, article analysis citing/referencing articles, research trend analysis, and topic development/future research analysis.

The novelty analysis I conducted revealed a major paradox in the current state of research: while liquid waste pollution and environmental policy were some of the most rapidly growing research areas in publications starting in 2024 - 2025, there existed very few bibliometric analyses of these fields, and even fewer were found that attempted to visualize the interconnectedness of the two fields. These findings show a gap in the growth of research volume and the appropriate analytical methodologies used to tackle the contradictions and complexities present in the science policy interface. One indicator that the volume and citation growth is because bibliometric research is sorely needed in the field, and it demonstrates the strategic position of this research to fill a gap in neglected research. The newly achieved balance in this research reflects growth in the field of study and a call for unprecedented methodologies that tackle complex scientific phenomena and present them in a comprehensible way for policymakers.

3.2 Country/Region Analysis

Out of the total of 73 countries/regions analyzed in this field, some countries are more productive and collaborative than others, though the data can be examined in more detail. As shown in Figure 4A, China is the most productive country with 56 publications,

*Corresponding Author: washillaaudia@student.unp.ac.id

followed by the United States, which has 40 publications, and the United Kingdom with 25 publications in third place. However, there is not always a strong relationship between the amount of productivity and the degree of collaboration. China has a much larger number of publications in addition to the number of citations (1,914) to their publications. However, their Total Link Strength (TLS) is 34. This is lower than the United Kingdom, which has the greatest TLS of 38, but with less publications. This shows that the United Kingdom has a greater degree of collaboration and, therefore, a much stronger collaborative network than China. Because despite their productivity and their influence, China does not have a collaboration network that would be expected. As reported, the international collaboration network (Figure 4B) consists of 73 countries and is represented by 170 links which is an overall TLS of 208.

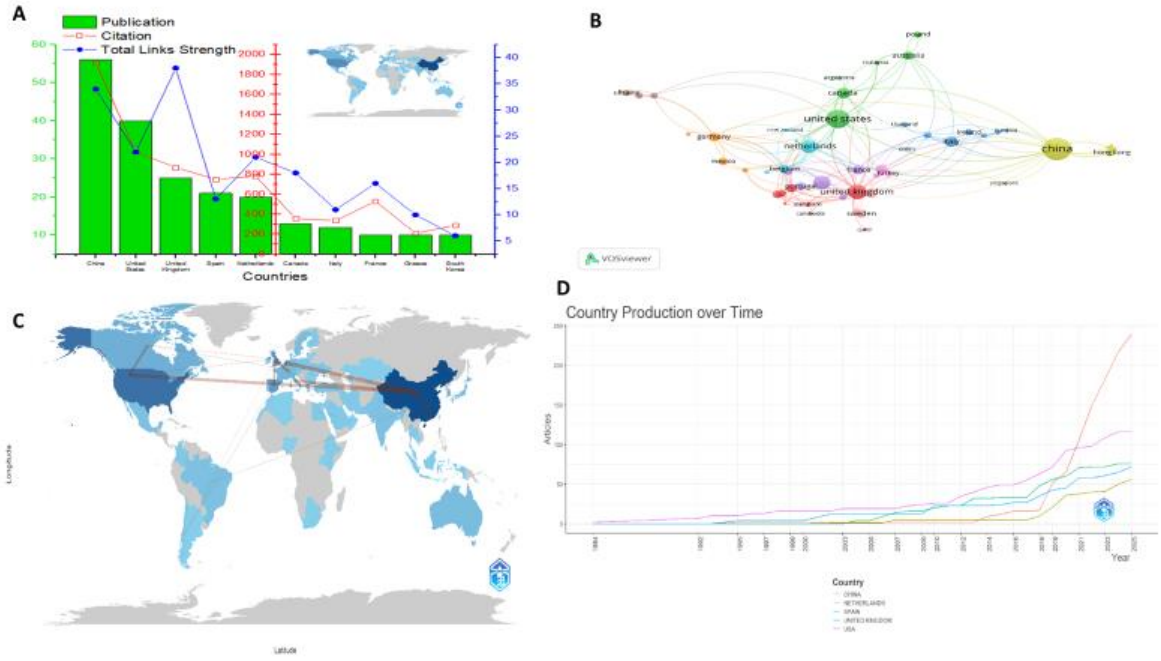

Fig 4. (A) Publications, Links, and Total Links Strength (TLS) for the Top 10 Countries Based on Number of Publications (B) Map of International Cooperation in Document Publishing (C) Map of International Collaboration (D) Article Production by Region Over Time

The phenomenon of polarization can be seen in 10 specific clusters (see Figure 4C), where each of the clusters represents a community of collaboration that has strong and close cohesion. This arrangement reflects the emergence of certain “knowledge blocks” in the world, where certain countries tend to collaborate and work together. Key countries like China are becoming increasingly dominant, owing to their position as a major center with 20 collaboration partners. On the other hand, the increase in the number of publications in the world from the top 10 countries, as presented in Figure 4D, corroborates that the problems of analyzing liquid waste contamination and developing regulatory policy are becoming more urgent and recognized worldwide. This field of research, with China as the hub and many countries actively participating, is highly relevant and shows great promise for the future.

*Corresponding Author: washillaaudia@student.unp.ac.id

3.3 Institutional Analysis

The number of registered participants for this study includes 463 organizations showcasing a very active collaboration. The productivity of the leading 10 participants is displayed in Figure 5A with a breakdown of the productivity of the participants over the years in Figure 5B. In terms of productivity, the top reported participant is Nanjing University, situated in China, with 23 articles, which is 18.85% of all publications for the top 10 participants. In addition to this productivity, Nanjing University also displays a strong collaborative relationship with a number of prestigious co-partners, enhancing the university's status as a significant research core. The significance of this data shows, not only that the research field is very much alive in all dimensions, but also that this research field is in strong growth, with a widening interest all over the world.

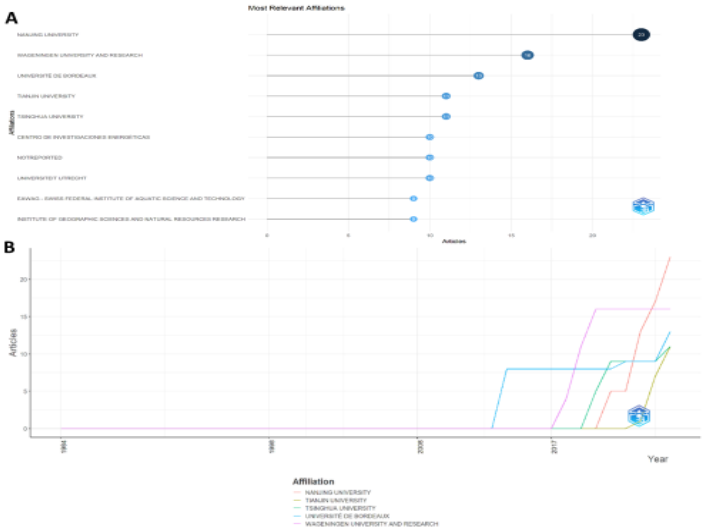

Fig 5. (A) Number of Publications by the Top 10 Institutions (B) Analysis of Institutional Production Over Time

3.4 Author Analysis

The impact on this domain is a result of the research efforts of 1216 authors, of which productivity over time (Figure 6A) shows performance from the top ten authors. We conducted an extensive investigation and retrieved three notable authors, Kroeze Carolien, Ma Lin and Strokal Maryna Petrivna, each with three publications on the 2019-2020 focus of the research and together received 107 citations. On the other hand, Beusen Arthur HW, with a smaller volume of work, had the highest scientific impact with 214 citations. In total, these three authors together produced nine publications over the time of the study (Figure 6B) and their collaborations over time are sketched in Figure 6C. Their positions and institutions are detailed in Table 2 which shows a distinct spatial collaboration between the Netherlands and China. The predominance of these two countries is clear and shows that their leadership in science is the result of considerable productivity and the capacity of that work to create impact.

*Corresponding Author: washillaaudia@student.unp.ac.id

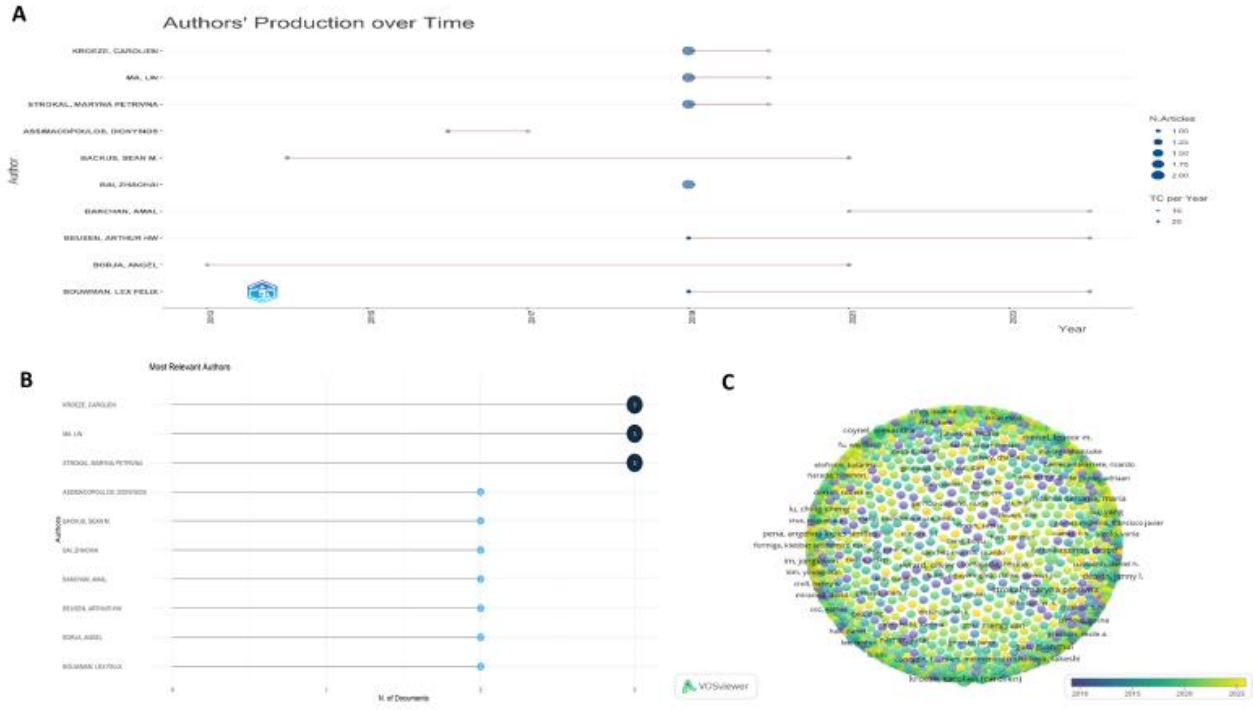

Fig 6. (A) Map of Author Production Over Time (B) Ten Most Productive Authors (C) Map of Author Collaboration Networks

Table 2. Ten Most Productive Authors in Research Analysis of Technology Integration in Environmental Pollution Detection

Rank	Author	Publication	Citations	Institution
1	Kroeze, Carolien	3	107	Water Systems and Global Change Group, Wageningen University & Research, P.O. Box 47, 6700 AA, Wageningen, The Netherlands.
2	Ma, Lin	3	107	Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetic and Developmental Biology, The Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang 050021, Hebei, China
3	Strokal, Maryna Petrivna	3	107	Water systems and Global Change Group, Wageningen University & Research, Droevendaalsesteeg 3, Wageningen, 6780 PB, The Netherlands

*Corresponding Author: washillaaudia@student.unp.ac.id

4	Assimacopoulos, Dionysios	2	84	National Technical University of Athens (NTUA), School of Chemical Engineering, Environmental and Energy Management Research Unit, 9, Heroon Polytechneiou, Zografou Campus, 15780, Athens, Greece
5	Backus, Sean M.	2	114	Strategic Policy Branch, Environment and Climate Change Canada, Burlington, Ontario L7S 1A1, Canada
6	Bai, Zhaohai	2	96	Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetic and Developmental Biology, The Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang 050021, Hebei, China
7	Bakchan, Amal	2	20	Civil, Architectural and Environmental Engineering, The University of Texas at Austin, 301 East Dean Keaton Street C1752, Austin, Texas 78712, United States
8	Beusen, Arthur HW	2	214	Department of Earth Sciences - Geochemistry, Faculty of Geosciences, Utrecht University, P.O. Box 80021, 3508 TA Utrecht, the Netherlands; PBL Netherlands Environmental Assessment Agency, P.O. Box 30314, 2500 GH The Hague, the Netherlands.
9	Borja, Angel	2	61	AZTI, Marine Research, Basque Research and Technology Alliance (BRTA), Herrera Kaia, Portualdea z/g, 20110, Pasaia, Spain.
10	Bouwman, Lex Felix	2	214	Department of Earth Sciences - Geochemistry, Faculty of Geosciences, Utrecht University, P.O. Box 80021, 3508 TA Utrecht, the Netherlands; PBL Netherlands Environmental Assessment Agency, P.O. Box 30314, 2500 GH The Hague, the Netherlands.

*Corresponding Author: washillaaudia@student.unp.ac.id

3.5 Analysis of Journals and Frequently Cited Journals Together

This line of analysis has appeared in 134 journals, with an overlap map (Figure 7A) illustrating how much each publisher has contributed. The higher numbers of yellow nodes indicate that the research dynamics are still growing, as are the numbers of newly published works. The analysis of the top ten journals (Figure 7C) shows that Science of The Total Environment has the most articles (36), followed by the Journal of Environmental Management (18). The concentration of publications in these journals in combination with the high impact factor, reflects not only the quality of the research, but also the extent to which the themes relating to the analysis of wastewater and its associated policy frameworks are now highly pertinent within the field of environmental science and sustainability. The time series analysis for the journals of this field (Figure 7B) shows that Science of The Total Environment has markedly higher volume of publications than any other journal, with the most publications in the period 2010-2025. Furthermore, Science of The Total Environment shows high rates of productivity for the period 2010-2025, with the most publications residing within 2010-2025 due to the rapid increase in productivity from only 1 published paper in 2010 to 4 in 2016 and maintaining high productivity with an eventual total of 36 publications. This increase demonstrates that this field is still emerging, and there are signs that there is a shift towards liquid waste-based approaches and environmental policy and their implementation as a means to address significant and tangible pollution. Therefore, this publication profile chronicles the evolution of research themes from the technological dimension to the policy dimension, and also illustrates the scientific response to the growing environmental concerns around the world.

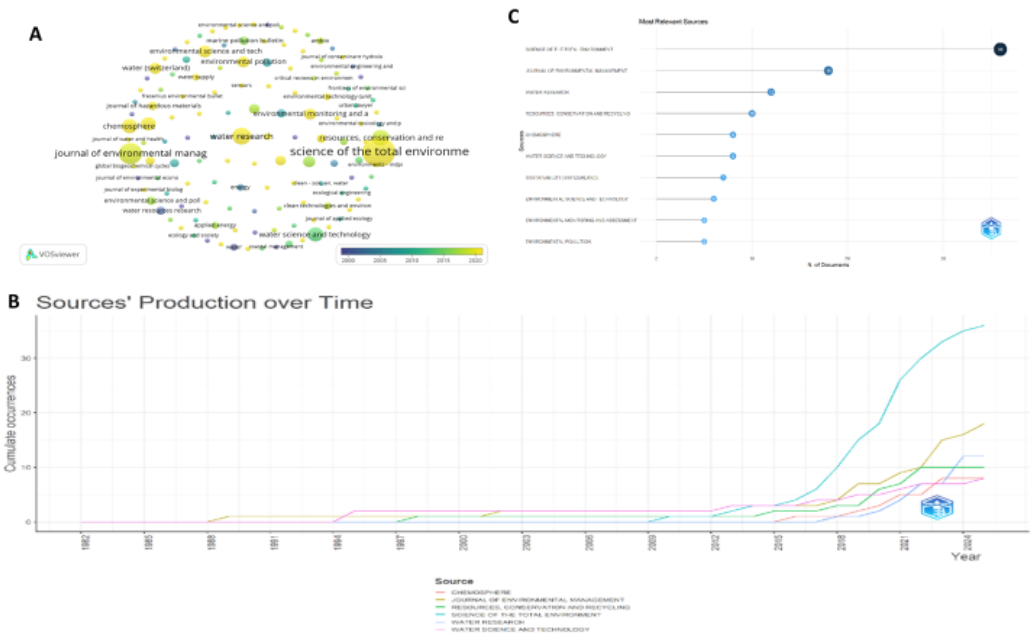

Fig 7. (A) Visualization Map of Overlapping Citations Between Journals (B) Five Most Productive Journals (C) 10 Most Productive Journals in Research Analysis in This Field

*Corresponding Author: washillaaudia@student.unp.ac.id

3.6 Keyword-Based Research Trend Analysis

Bibliometric assessments of 4422 terms using VOSviewer captured the intellectual breadth and state of the art of the field and optimized the data set down to the 1000 most pertinent terms. Network mapping (Figure 8A) shows tiered relationships to the core concepts of the field. Core to this is ‘environmental policy’ and its variants as the most dominant concept (n=228) which is also evidenced in the word cloud in Figure 8B. The extent of temporal depth of the analysis is clear from the trend map in Figure 8C which clusters the top 10 keywords with the strongest cited increases (spikes) from Figure 8D. Figure 8C also shows ‘environmental policy’ scholarly works development ‘exploded’ from 3 occurrences (1993) to 228 (2025) as did ‘wastewater treatment’ from 8 (1998) to 215 (2025). The depth also stands alone from the mere increase in research volume and this points to the narrowing of focus in the scholarly field on the major problem of environmental pollution evidenced by the depth of research. The finding is further confirmed with theme or concept Treemap in Figure 8E which shows spatial mapping with the preeminent topics of environmental policy and wastewater treatment. The presence of these keywords, particularly “wastewater” and “environmental protection”, alongside the aforementioned quantitative dominance, suggests a shift from the traditional to the technologically advanced. Therefore, this keyword map captures the state of affairs, while also functioning as a beacon of innovation, both in the formulation of policy and the integration of technologies to address the challenges of the environment sustainably.

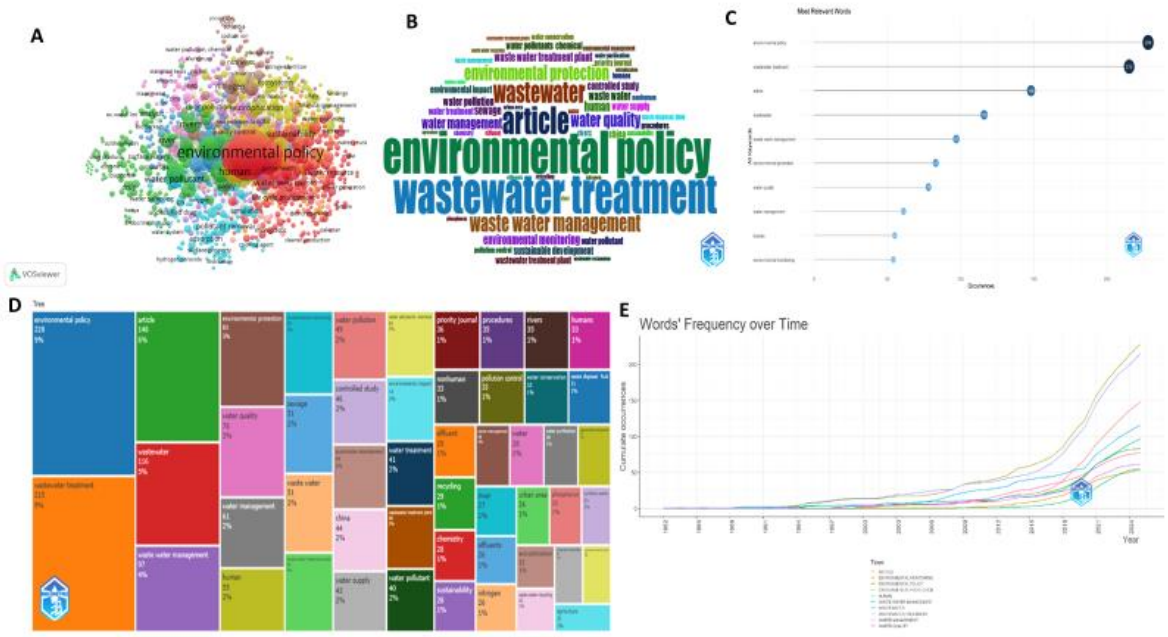

Fig 8. (A) Visualization Map of Keyword Overlap (B) Wordcloud (C) Top 10 Keywords with the Strongest Spike in Citations (D) Treemaps of Keyword Occurrence (E) Frequency of Keyword Occurrence Over Time

*Corresponding Author: washillaaudia@student.unp.ac.id

3.7 Discussion

The project "'Bibliometrics and Visualization of Liquid Waste Contamination Analysis and Environmental Policy Development"" focuses on quantitative scholarly outputs and graphical representations of liquid waste and environmental policy development and their interconnections. This is a multidisciplinary area where bibliometric techniques are employed to track liquid waste consummation and its\' management. This includes mapping scholarly output, describing influential players, and revealing gaps in the liquid waste substantially and its management literature (Elshaboury et al., 2022; Jumilah et al., 2025, Nurdini et al., 2023, París Paricio et al., 2025, Rafiq et al., 2023b, Rahaman et al., 2022, Reis et al., 2023). At the same time, the use of different techniques to assess the data and information makes the findings and ideas comprehensible to the already entrenched scholars and policymakers (Anusha et al., 2024; Ayub et al., 2024; Chicaiza-Ortiz et al., 2024; Harfadli et al., 2024; Islam et al., 2024; Kala and Bolia, 2024; Mubin et al., 2024; Neto et al., 2024; Qin et al., 2024; Rayhan and Bhuiyan, 2024; Weets and Katz, 2024; Wei et al., 2024; Xie et al., 2024; Xu et al., 2025; Zhou, 2024).

As Scopus and Streamline are huge databases with numerous records, they are valuable resource in obtaining bibliometric information. Scopus is frequently used in environmental and sustainability studies, and waste management focuses on the retrieval and the analysis of the data, capturing the main themes, authors, and trends of the studies (Baas et al., 2020; Dong et al., 2021; Hidayati et al., 2025; Kumar et al., 2024; Pham et al., 2021; Thu et al., 2021; Yirci et al., 2023). Concerning liquid waste, that means determining the premier authors and the foremost countries and institutions in the field on the studies of techniques of contamination assessment and treatment (París Paricio et al., 2025). A bibliometric study using Scopus, Web of Science, and Google Scholar about 234 peer-reviewed articles published from the year 2000 to 2023 on global trends in research pertaining to the organic waste enzymes for plastic biodegradation is Nizar, 2025b. Research studies in maintaining municipal solid waste and management (MSWM) conduct systematic reviews and bibliometric analysis of the literature. In these studies, the authors ascertain all the various frameworks and instruments used in the collection systems to balance the optimization of the collection systems (Neto, 2024). This approach analyzes the research output and identifies highly cited documents and predictive topics of the research domain.

Determining actionable knowledge is possible through visualization in bibliometric studies. Keyword co-occurrence, co-authorship, and thematic evolution map the intellectual structure, and the networks of the research collaborations and visualization Pham et al. (2021). VOS Viewer is one of the most referenced tools for bibliometric map visualization (Judijanto, 2025b; Kumar et al. 2024). This tool can illustrate the networks of different issues of liquid waste such as the microplastic transport in porous media (Jiang et al., 2021) and the organochlorine pesticide distribution in water (Vudamala et al. 2023). The transport of microplastics, mainly polypropylene and polyethylene, has also gained interest. The visualization of the inline studies can demonstrate how increased surfactant

*Corresponding Author: washillaaudia@student.unp.ac.id

concentration during migration can enhance the pollution scope (Jiang et al. 2021) VOS Viewer has also been used in other cases such as marine plastic pollution global research, where the author collaboration networks, keyword co-occurrence and theme evolution derived from the Scopus dataset were analyzed (Judijanto, 2025a).

The amalgamation of bibliometric methods and visual representation is essential to formulating pertinent policies in the environmental domain. Policies aimed at liquid wastes like domestic sewage disposal, monitoring water quality, and discharging pollutants are significant to human and ecological wellbeing. (Weets & Katz, 2024). A global cartographic representation of these policies can be visualized effectively, showing the areas with policies and those with absence of such policies (Weets & Katz, 2024).

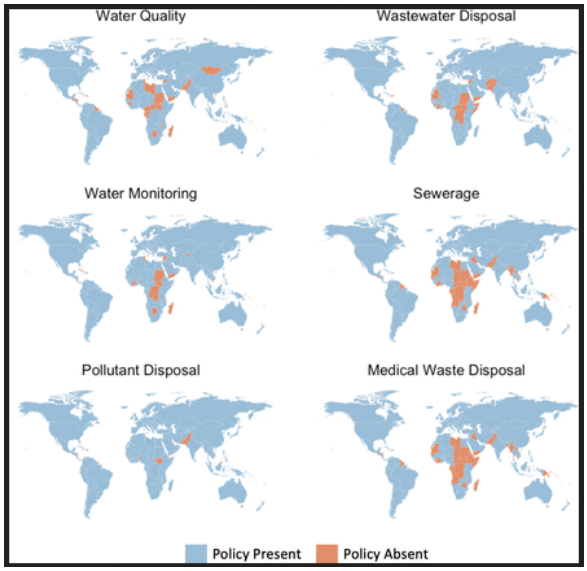

Fig 9. Water and Waste Management Policy (source: Weets & Katz, 2024)

In the 2024 study by Weets and Katz, the authors present various global policies on water and waste management, such as water quality, wastewater, water monitoring, waste management, discharge of pollutants, and medical waste management (see Fig 9). Weets and Katz (2024) provide light blue shades for countries that have these policies, and use orange for countries with no such policies at all. This map shows no policies and the no policies map can support international target setting and the prioritization of international resources for the environment (Weets & Katz, 2024).

Visual representations may aid in the identification of regions of evidence substantiated scientific knowledge. In contrast to regions of knowledge where abandonment of evidence is required in support of policymaking. In contrast to regions of knowledge where abandonment of evidence is required. (Qin et al., 2024) (Xu et al., 2025). An example is the framework of the Evolution of Waste Management Policy in China, which illustrates the contribution of Policy Analysis, and Content Analysis, and the Understanding of Policy The Dynamics and the Objectives - Instruments Relationship. (Qin et al., 2024).

*Corresponding Author: washillaaudia@student.unp.ac.id

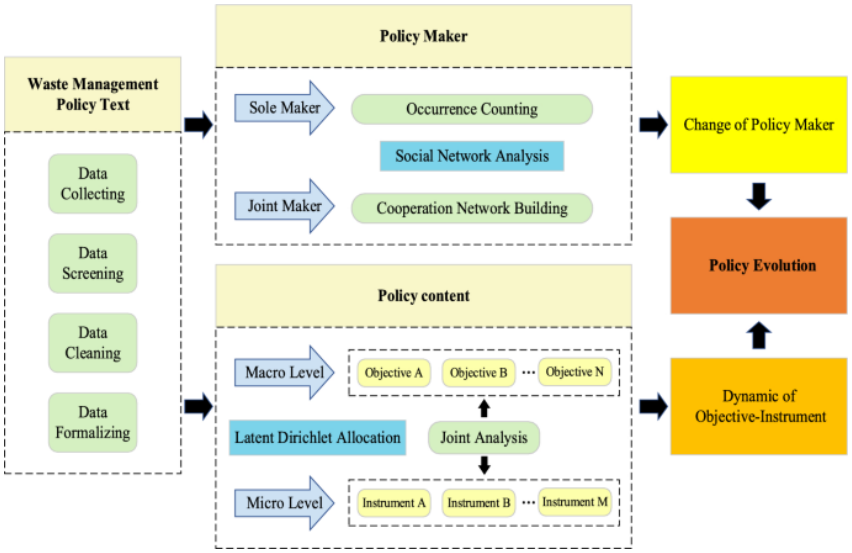

Fig 10. Waste Management Policy Analysis (source: Qin et al., 2024)

According to Qin et al. (2024), the framework in Figure 10 outlines the sequence of operations which involves analyzing policies in waste management beginning with obtaining primary data and processing the information, then moving towards the analysis of the decision-maker, (that is, of either a single and/or a multiple policy maker), and finally, the analysis of the content of the policies (involving the macro objectives and micro instruments). This approach makes it possible to appreciate the evolution of a policy and the interplay between the objectives of the policy and the mechanisms employed to attain the objectives. Additionally, one can utilize bibliometrics to measure the effects of a particular policy on the environment in relation to the shift in the focus of the research following the enactment of the policy. One such example is the increased focus on an ecological civilization in China, which has subsequently been translated into a greater number of policies on Environmental Education (EE), particularly on the waste classification in primary school (Zhou, 2024).

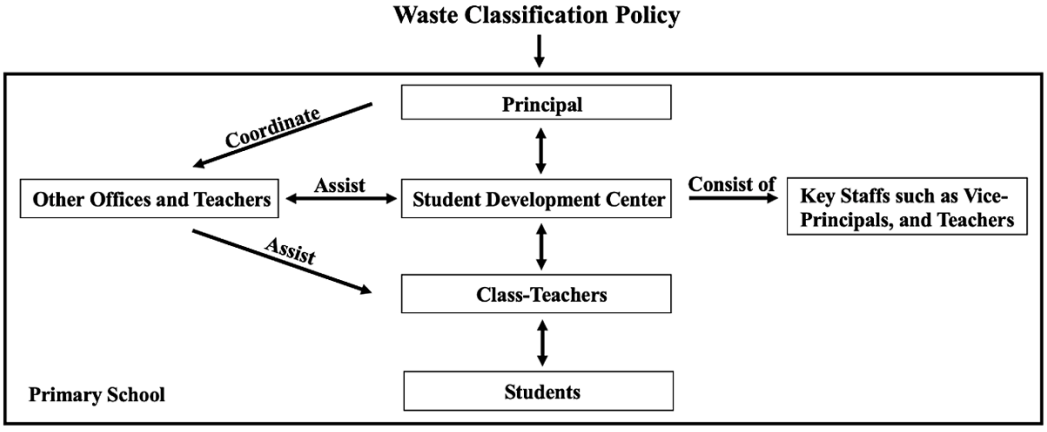

Fig 11. Waste Classification Policy (source: Zhou, 2024)

According to Zhou (2024) there are different levels of management in elementary schools who have overlapping responsibilities in the implementation of waste separation policies such as principals, staff, teachers, and students as illustrated in Figure 11. Coordinated efforts are required to integrate and apply environmental education, as Zhou (2024) indicates. Liquid waste management challenges are, in themselves, complicated.

*Corresponding Author: washillaaudia@student.unp.ac.id

For example, there microplastics pollution in estuaries (Q. Zhang et al., 2022) and there are difficulties in obtaining short-chain fatty acids through the digestion of sewage sludge. Unregulated informal waste sectors in developing countries are often the most impacted, even though they play the most critical role.

Chen et al. (2021), and Rayhan and Bhuiyan (2024) recognize the increasing number of analyses in the field of waste to energy (WtE) technologies, sustainable waste management, and the valorization of waste. It is also worth noting the expanding construction and demolition waste management. Such analyses help to identify success factors in the field of waste separation (Xie et al., 2024) and construction waste separation, through the use of dynamic simulation, to determine the potential of carbon offsets through the construction waste separation.

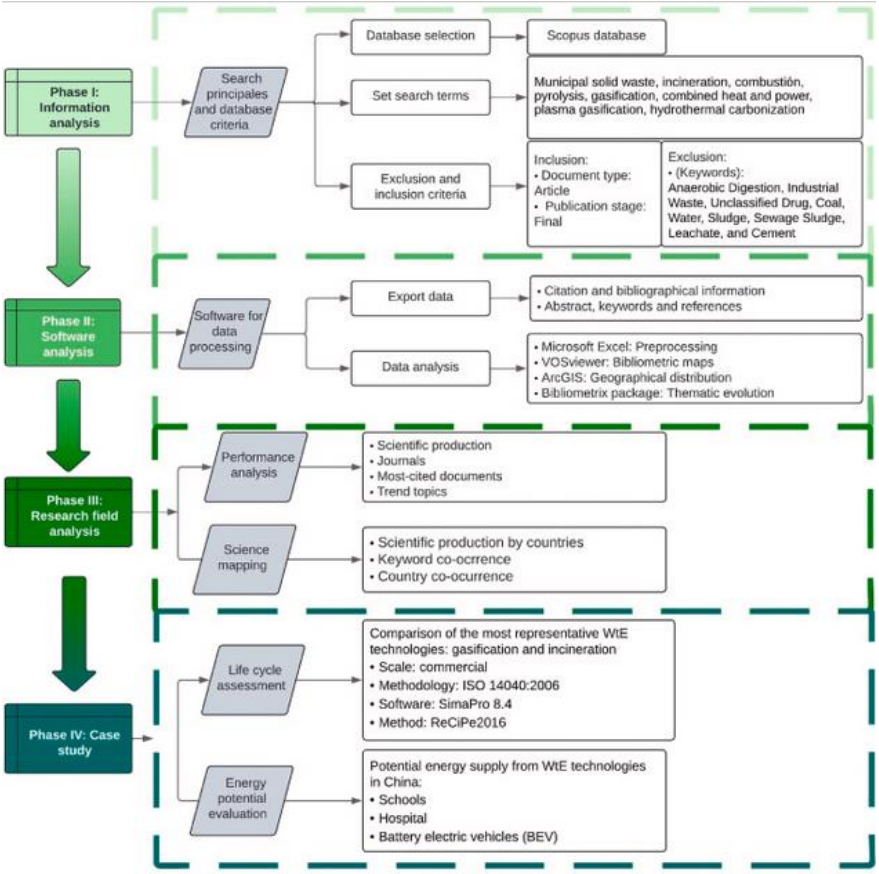

Fig 12. Research Methodology for Waste-to-Energy Conversion (source: Chicaiza-Ortiz et al., 2024)

The methodology for performing bibliometric analysis and life cycle assessment on waste-to-energy (WtE) technology including sourcing Scopus, software analytic (VOSViewer, ArcGIS), domain analysis, and energy potential case studies are explained in Chicaiza-Ortiz et al, (2024), illustrated in Figure 12. Such coordination gives a clear picture of the potential direction of WtE research and WtE technologies (Chicaiza-Ortiz et al, 2024).

This article focuses on the pressing need for policy makers to be evidence-based and backed with solid science. Academics can work to analyze outputs thoroughly and depict data in a way that allows policymakers and theorists to tackle emergent themes,

*Corresponding Author: washillaaudia@student.unp.ac.id

measure policy success, and design more effective environmental liquid waste policies. Such work describes the state of the art and specifies knowledge that can guide research and the rational allocation of resources for the purposes of sustainable waste management (Espuny et al, 2021).

CONCLUSION

A thorough bibliometric analysis of 285 scholarly works allows this investigation to trace the intellectual landscape and the pivot point in scholarly interest on the intersection of liquid waste contamination and the development of associated environmental policy. There is a noted increase after 2014 wherein 75.78 % of the works were published in the last decade. This is a disappointment for the increasing global urgency with the ongoing water pollution crisis. It is fitting to be expected that in this research field, China is the epicenter with the most published works in the field at 56 and 1914 cited works, and serves as the country of collaboration, as a result of the leadership and investment in environmental governance. In contrast, the other world countries clustering in the 10 other countries formed a collaborative unit of these clusters singularise a set of "knowledge blocks" that resulted in a less unified global discourse on the new field. It is the primary and secondary environmental policy framing that this field of research is grounded on, with a pivot as evidenced by the anticipated shift towards less technocratic policy mechanisms, and more integrated policy.

The droves are of publications occurring without policy adaptation in tandem with them, indicating a disconnect between scientific advancements and the ability to utilize them in policy formation. This study, however, identifies three of the most pressing analytical gaps in policy design to be addressed immediately. First is the policy abandonment gap, where there is a failure to convert policy prescriptions from the laboratory. Second is the need of a dynamic policy mechanism to address the newly emerging paradigm of pollutants such as PPCPs and microplastics. Third is the need for the newly proposed policy collaborative capacity to address the siloed, fragmented global research networks. In addressing the above, this study contributes to a roadmap for future research in the stabilization of enzymes, the scaling of technologies, and policy integration, and provides policy makers new avenues to construct legitimate, more integrated responses to the complexities of managing environmental governance and wastewater pollution.

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*Corresponding Author: washillaaudia@student.unp.ac.id

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*Corresponding Author: washillaaudia@student.unp.ac.id