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Review Article

Trends and Patterns of Sediment Contamination in Indonesia (1999-2024): A Scientometric Analysis

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Abstract

In the current era of the Industrial Revolution, there is a substantial increase in effluents from industrial discharges and domestic waste flowing into the sea, leading to contamination of water bodies. This includes pollutants such as heavy metals (Cu, Pb, and Zn) and microplastics, which eventually settle and contaminate sediments. Research on sediment contamination in Indonesia has been quite numerous and varied, but none has employed the scientometric method to analyze the trend of sediment contamination. Using CiteSpace, this study analyzes trends and patterns in research topics, citation frequency, and publication numbers over the past 25 years, based on co-occurrence, co-word, and co-citation analyses. The study examined 177 research articles indexed by Scopus. Findings reveal substantial international collaboration, with Indonesia leading with 167 publications, Malaysia with 19, and Japan with 15, showing a significant gap. The research spans various subject areas, including Environmental Science (111 articles), Earth and Planetary Sciences (74 articles), and Agricultural and Biological Sciences (55 articles). This study will provide a quantitative and visual overview of sediment contamination research in Indonesia, offering a comprehensive discussion of the findings.

Keywords: Sediment contamination; scientometric; pollution; heavy metals

1. Introduction

Water covers approximately 71% of the Earth's surface, with seawater comprising the majority, as reported by the National Ground Water Association. As the population grows and time progresses (He, 2024), human settlements are gradually encroaching upon coastal areas, inevitably moving closer to the sea. In the current era of the Industrial Revolution, there is a substantial increase in effluents from industrial discharges and domestic waste flowing into the sea, leading to contamination of water bodies. This pollution impacts many marine organisms and ecosystems (Lestari & Trihadiningrum, 2019), making marine pollution an unavoidable issue in this developing situation. Marine pollutants such as heavy metals (Cu, Pb, and Zn) and microplastics, eventually settle and contaminate sediments. Contaminants in sediments stem from multiple sources, including agriculture, aquaculture, water transport, and coastal activities (Rozirwan et al., 2024). Human activities impact water quality in several ways, including sediment settling. Sand-sized sediment particles indicate stronger hydrodynamic energy as opposed to other sediment sizes (Rosyadewi & Hidayah, 2020). Heavy metal contamination in sediments is a major concern in developing countries. Household and industrial wastewater, chemicals, and refining industries are primary sources of this contamination (Yap & Al-Mutairi, 2021). The substantial volume of industrial solid waste has been noted to affect the marine debris entering the ocean (Lestari & Trihadiningrum, 2019) evidenced by research conducted in Jakarta Bay. Moreover, microplastics have been detected in both water bodies and sediments, as well as in organisms like fish. Studies in ASEAN countries revealed that these areas are polluted with microplastics (Gabisa & Gheewala, 2022; Li et al., 2023; Yang et al., 2021).

Extensive research has been conducted on sediment contamination, particularly in Indonesia. While many articles employ systematic, critical, and in-depth reviews, it would be valuable to investigate the trends in sediment contamination in an ASEAN country like Indonesia, considering the numerous studies indicating various pollutants. Additionally, there is currently no review of articles on sediment contamination that utilizes the scientometric analysis method using CiteSpace.

Using CiteSpace, this study endeavor to analyze trends and patterns in research topics, citation frequency, and publication numbers over the past 25 years, based on co-occurrence, co-word, and co-citation analyses. The exact relationships between keywords and citations will be identified in the form of trends. The quality of an article can be determined by how often it is cited. Additionally, the study will reveal which countries collaborate on articles related to sediment contamination.

2. Methods

This study used Scopus as the database, with the keywords "sediment" AND "contamination" OR "pollution" OR "taint" AND "Indonesia." The search was limited to 25 years from 1999 to 2024, and included only English-language articles and open-access conference papers. As shown in **Figure 1,** these criteria yielded 177 results.

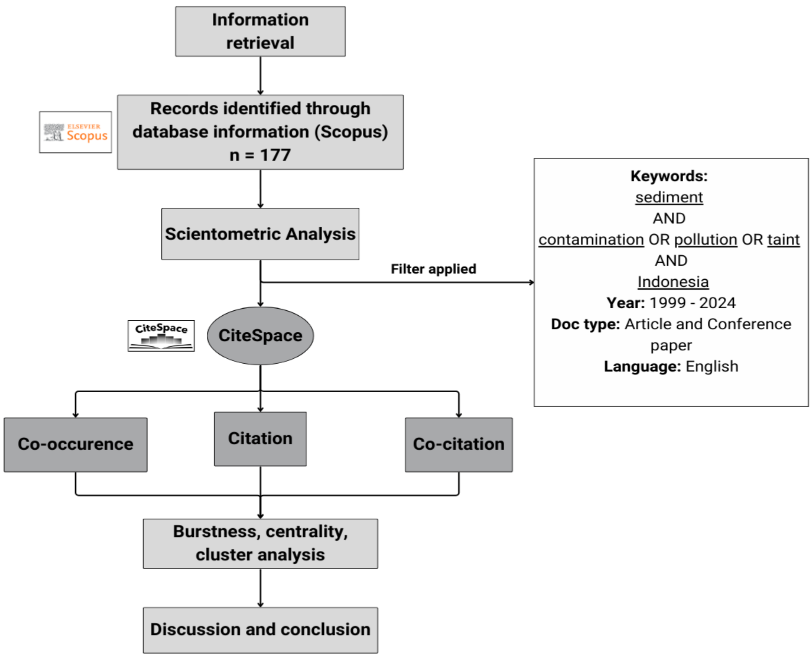


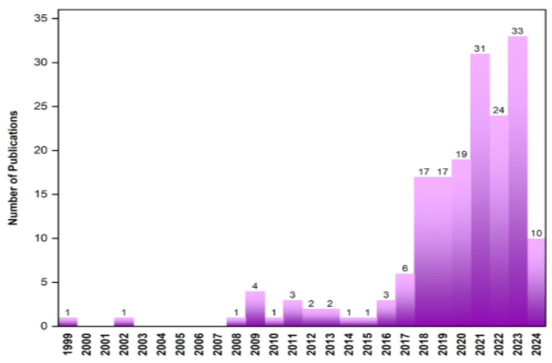
Figure 1. Flowchart of comprehensive procedures for scientometric analysis

The articles will be reviewed using scientometric methods with Citespace. Visualization using CiteSpace reveals trends and patterns in the collected literature, such as publication distribution, author relationships, co-citation networks, and recurring keyword clusters. This information helps identify main topics, research development, and connections between relevant concepts or disciplines. To ensure the analysis is unbiased, the results are validated by checking the consistency of findings across parameters like time range and geographic area, while also addressing potential data imbalances such as period or author group dominance. Facilitated by the CiteSpace application, co-occurrence, citation, and co-citation analysis will be performed. Co-occurrence analysis assesses the similarity between keywords by analyzing their frequency of appearing together in a collection of literature (Zheng et al., 2020). Co-citation demonstrates active cooperation between researchers through citation. Co-citation is a connection formed by citing authors. Measuring co-citation strength can be used to evaluate the level of association between papers as perceived by these authors (Budihardjo et al., 2021). The research cluster includes the set of cited articles representing the research foundation and the assortment of articles grouped by similar keywords according to the algorithm. This process generates a citation cluster timeline, highlighting correlations between co-citation, clusters, and time (Shen et al., 2023; Small, 1973; Song et al., 2022). Besides cluster analysis, CiteSpace also identifies burstness and centrality. Centrality indicates the significance of the literature; the higher the centrality, the more frequently an article is cited. The burstness indicator is determined using the time variable, revealing the years when the article is most extensively cited (Shen et al., 2023).

3. Result and Disscusion

3.1 Data Retrieval

Referring to the method employed by (Zheng et al., 2020), the screening identified 177 Scopus-indexed articles related to sediment contamination in Indonesia. Figure 2a shows the progression of publications on sediment contamination in Indonesia between 1999 and 2024. From 1999 to 2015, the number of publications was consistently low, with most years yielding only one or no publications. A significant rise in publications began in 2016, reaching its highest point in 2023 with 33 studies, reflecting an increasing focus on sediment contamination likely driven by environmental concerns and policy advancements. Figure 2b highlights the distribution of publications across countries, with Indonesia contributing the overwhelming majority (167 documents), indicating its central role in this research domain. Malaysia (19 documents) and Japan (15 documents) follow, although their contributions are much smaller. Most other countries contribute minimally, with only one to four publications each. This disparity highlights Indonesia's central role and its strong engagement with sediment contamination research. Together, these figures reveal both a temporal expansion of the research and a geographically concentrated effort, predominantly led by Indonesia and regional countries. A total exceeding 177 indicates the presence of international collaboration in publications, allowing multiple countries to be included in collaborative research (Shen et al., 2023).



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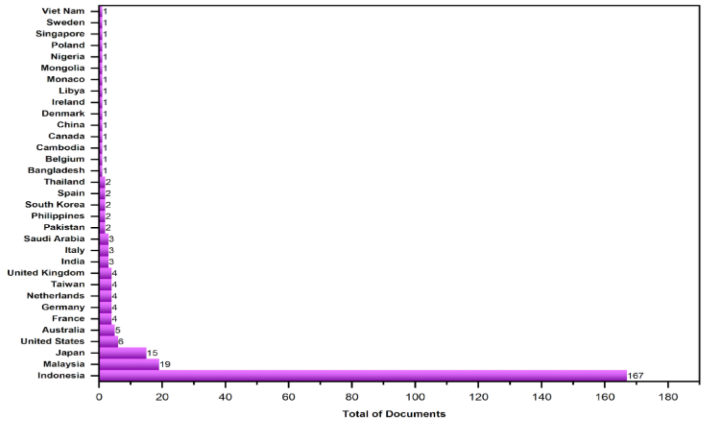
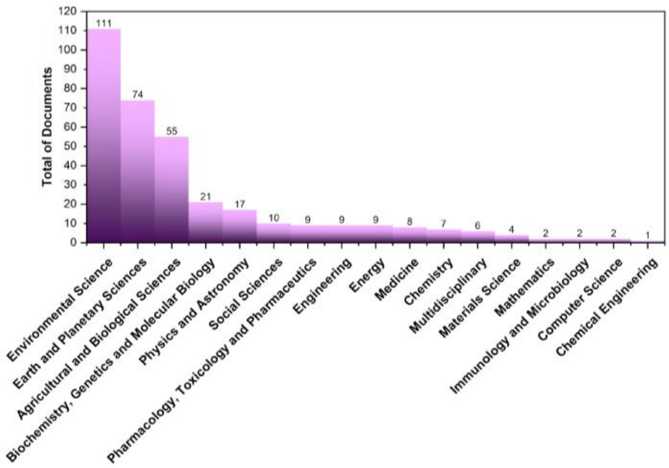


(b)

Figure 2. (a) Source documents categorized by year of publication, (b) countries engaged in publications on sediment contamination



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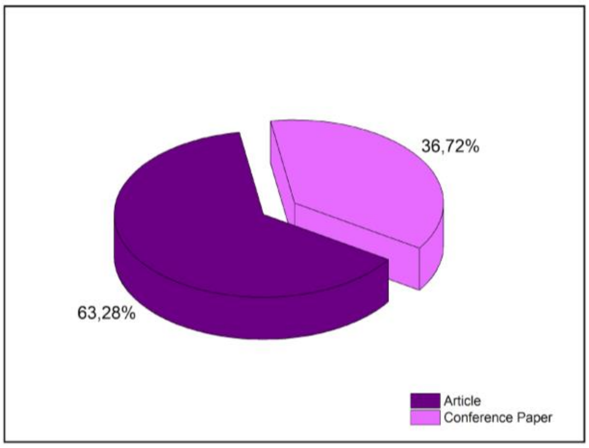


(b)

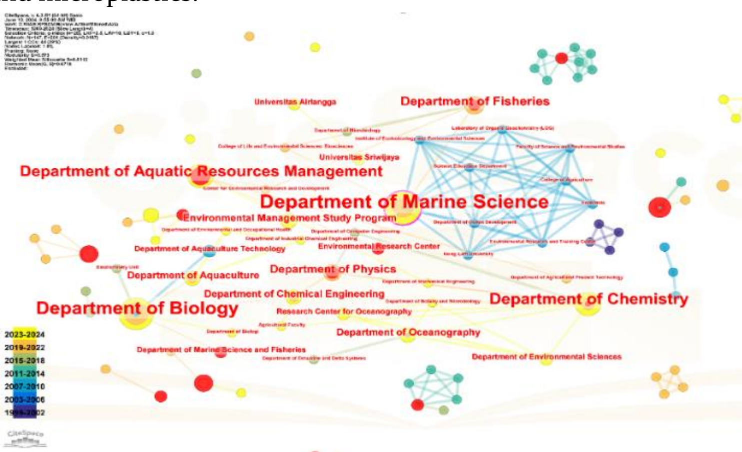
Figure 3. (a) Subject areas involved in the contamination of sediment, (b) records classified by their type

Figure 3a displays the distribution of subject areas contributing to sediment contamination research. Environmental Science dominates the field with 111 publications, reflecting the primary focus on ecological impacts and sustainability. Earth and Planetary Sciences follow with 74 publications, emphasizing geological and sedimentary processes. Agricultural and Biological Sciences contribute 55 publications, reflecting the connection between sediment contamination and agricultural or ecosystem health. Other fields, such as Biochemistry, Genetics, and Molecular Biology (21 publications) and Physics and Astronomy (17 publications), provide additional interdisciplinary insights. Smaller contributions from Social Sciences, Engineering, and Energy, each with 9 to 10 publications, reveal broader implications for society and technology. Similar to the analysis of countries, subject areas with more than 177 documents indicate collaboration or closely related topics (Shen et al., 2023) within those fields. The applied filter includes only open-access publications, which are further divided into four categories: gold, hybrid gold, bronze, and green open access. Among these, the gold open access category is the most prominent, accounting for over half of the studies analyzed, with a share of 51.5%. Figure 3b categorizes the document types, with journal articles making up the majority (63.28%), indicating a focus on detailed, peer-reviewed research. Conference papers make up 36.72%, reflecting the role of academic discussions and preliminary findings in advancing the field. These figures highlight the multidisciplinary nature of sediment contamination research, the dominance of environmental science, and a preference for journal publications over conference outputs.

3.2 Arising Trends in Sediment Contamination Research; Mapping Countries, Institutions, and Cited Authors

The network visualization map created by CiteSpace illustrates the connections between countries and institutions (Figure 4) engaged in research on sediment contamination in Indonesia. Figure 4a illustrates the institutions involved, where nodes represent the names of institutions, lines between nodes denote their relationships (Chen et al., 2021), and red circles highlight bursts. The Department of Marine Science ranks highest in citation counts and degree, with 16 citation counts and a degree of 19, clearly visible, making it the most prominent and largest node in the figure. Regarding bursts and sigma, the Department of Aquatic Resources Management leads, with bursts of 2.20 and a sigma of 1.23. In terms of centrality, the Department of Marine Science is the top-ranked with a centrality of 0.11, followed by the Department of Chemistry and the Department of Aquatic Resources Management, each with a centrality of 0.10. Indonesia, Malaysia, and Japan lead in the number of publications related to sediment contamination in Indonesia (Figure 4b). Indonesia ranks highest in both citation counts and centrality, with 165 citation counts and centrality of 1.28, highlighting its productivity in this research area. Malaysia has 19 citation counts, and Japan has 15 citation counts. Sigma denotes the network node of cited references to identify articles with high potential impact (Chen et al., 2012), the top three countries by sigma values are Malaysia (1.66), the United States (1.39), and Japan (1.10). Different colors on each node represent different years, as shown in the figure.

With the extensive research conducted within the Department of Marine Science, a common theme emerges, highlighting that sediment contamination frequently occurs in marine and coastal areas. Recent studies in Indonesia have identified that the highest contaminants are heavy metals such as Pb (Rozirwan et al., 2024), Fe, Al, and Cu (Fadlillah et al., 2023). The high levels of these heavy metals are attributed to various anthropogenic activities, including industrial operations (Analuddin et al., 2023), agriculture, and proximity to densely populated areas (Fadlillah et al., 2023). As shown in Figure 6, heavy metals form clusters, which are frequently discussed in research articles. Mangrove roots have been shown to help reduce heavy metal concentrations in areas where mangroves grow (Khotimah et al., 2024). In addition to heavy metals, microplastics have also been found in sediments (Moniuszko et al., 2023; Vidayanti & Retnaningdyah, 2024). The high concentration of microplastics is due to plastic waste that is not biodegradable and ends up in the ocean (Yona et al., 2024). This contamination not only affects sediment quality but also impacts marine life, such as fish (Elfidasari et al., 2023), which are affected by both heavy metals and microplastics.



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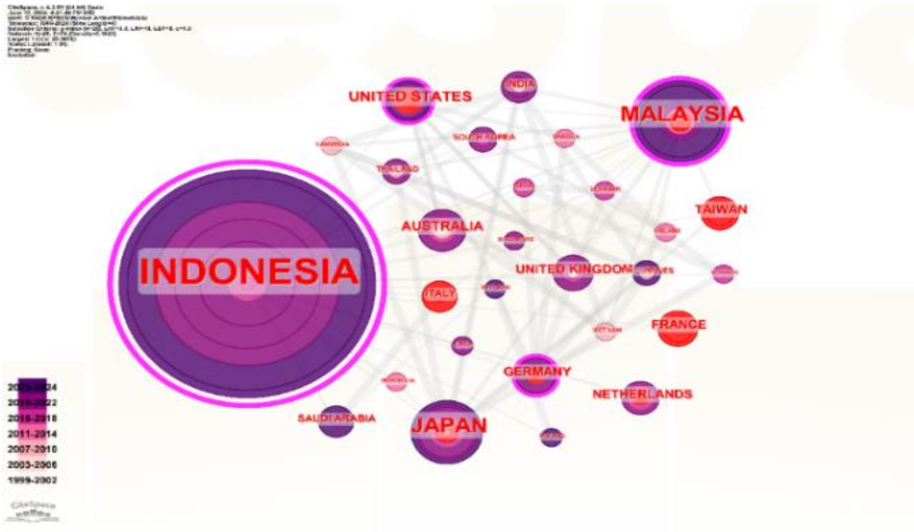

(b)

Figure 4. (a) Network visualization map by CiteSpace, showing a network of co-authors' institutions and (b) countries

The histogram in Table 1 highlights the top 15 authors with the strongest citation burst in sediment contamination research from 1999 to 2024. Burst strength reflects a significant increase in the number of citations for these articles (Chen et al., 2021). The top five bursts were observed between 2011 and 2014, indicating these years had a high frequency of cited articles. Different colors represent the years from 1999 to 2024, with red denoting the start and end years of the burst periods. The article with the highest citation count is Yona, with 5 citations. Authors such as Tanaka, Saito, Hosokawa, Yasuda, and Kurasaki showed notable citation bursts starting in 2011, with a strength of 1.13, which lasted until 2014, highlighting their influence during that period. Bouma and Christianen experienced slightly weaker bursts (0.86), extending until 2018. More recent contributions include Sakakibara and Sera, whose citation burst began in 2015 and continued until 2022, with Sakakibara showing a burst strength of 1.2. Recent authors like Yona and Sari demonstrated higher citation burst strengths (2.2 and 1.45) starting in 2019, reflecting their growing impact. Similarly, Indonesian authors like Muntholib, Hidayati, and Sabdono contribute to the growing research focus in Southeast Asia, with bursts extending from 2019 or 2020 to 2022.

Table 1. Top 15 cited authors with the strongest citation burst

Authors	Year	Strength	Begin	End	1999 – 2024
Tanaka, Shunitz	2011	1.13	**2011**	2014	
Saito, Takeshi	2011	1.13	**2011**	2014	
Hosokawa, Toshiyuki	2011	1.13	**2011**	2014	
Yasuda, Masaomi	2011	1.13	**2011**	2014	
Kurasaki, Masaaki	2011	1.13	**2011**	2014	
Bouma, TJ	2011	0.86	**2011**	2018	
Christianen, MJA	2011	0.86	**2011**	2018	
Sakakibara, Masayuki	2015	1.2	**2015**	2022	
Sera, Koichiro	2015	1.2	**2015**	2022	
Yona, Defri	2019	2.2	**2019**	2022	
Sari, Syarifah Hikmah Julinda	2019	1.45	**2019**	2022	
Wijaya, Anugrah Ricky	2019	1.19	**2019**	2022	
Muntholib, Muntholib	2019	1.19	**2019**	2022	

Authors	Year	Strength	Begin	End	1999 – 2024
Hidayati, Nuning Vita	2020	1.04	**2020**	2022	
Sabdono, Agus	2020	1.04	**2020**	2022	

3.3 Mapping co-occurences

The detected keywords are those frequently used by authors in their articles (Chen et al., 2021). The commonly appearing keywords are 'sedimentology', 'Eurasia', 'Asia', 'Southeast Asia', 'Indonesia', 'coastal water', 'metal', 'lead alloy', 'zinc', and 'anthropogenic effect'. **Table 2** shows the top keywords by strongest burst, with 'sedimentology' frequently appearing from 2008 to 2014 with a burst strength of 3.35. This is followed by 'Eurasia' and 'Asia', both with a burst strength of 2.96 from 2008 to 2010. The top-ranked item by citation counts is 'sediment' with a count of 77 and a centrality of 0.08, followed by 'Indonesia' and 'heavy metal' with 59 and 50 citation counts, respectively. The keyword 'Indonesia' exhibits notable significance, with a burst strength of 2.22 persisting from 2007 to 2018, reflecting its importance in this research area. Other terms, including 'coastal water' (2.16), 'metal' (2.04), 'lead alloy' (1.77), and 'zinc' (1.75), began bursts in 2008, underscoring a focus on metallic pollutants in environmental studies. 'Anthropogenic effect' appeared in 2009 with a burst strength of 1.72, lasting until 2014, highlighting interest in human-induced environmental impacts.

Table 2. Top 10 keywords categorized by the strongest burst

Keywords	Year	Strength	Begin	End	1999 – 2024
Sedimentology	2008	3.35	**2008**	2014	
Eurasia	2008	2.96	**2008**	2010	
Asia	2008	2.96	**2008**	2010	
Southeast Asia	2008	2.36	**2008**	2010	
Indonesia	1999	2.22	**2007**	2018	
Coastal water	2008	2.16	**2008**	2010	
Metal	2008	2.04	**2008**	2014	
Lead alloy	2008	1.77	**2008**	2010	
Zinc	2008	1.75	**2008**	2014	
Anthropogenic effect	2009	1.72	**2009**	2014	

Co-occurrence keywords were analyzed from 1999 to 2024, with a slice length of 4 years, as shown by the different colors for each slice year. The keywords are divided into 9 clusters, as depicted in Figure 5, with a modularity of 0.573 and a silhouette score of 0.8112, indicating a network size of 251. Modularity measures how well nodes are divided into distinct, interconnected groups. Each cluster represents a group of frequently appearing related keywords. For instance, cluster #0, 'coral reef', includes keywords such as 'calcitization', 'Jakarta', 'miocene', and 'coral triangle'. The newer the year, the darker the node color, ranging from yellow to brown. Connections between nodes signify relationships between keywords. The keyword 'sediment', which appears most frequently with 77 citation counts, is found in cluster #5, 'water', followed by 'Indonesia' and 'heavy metal' with 59 and 50 citation counts, respectively.

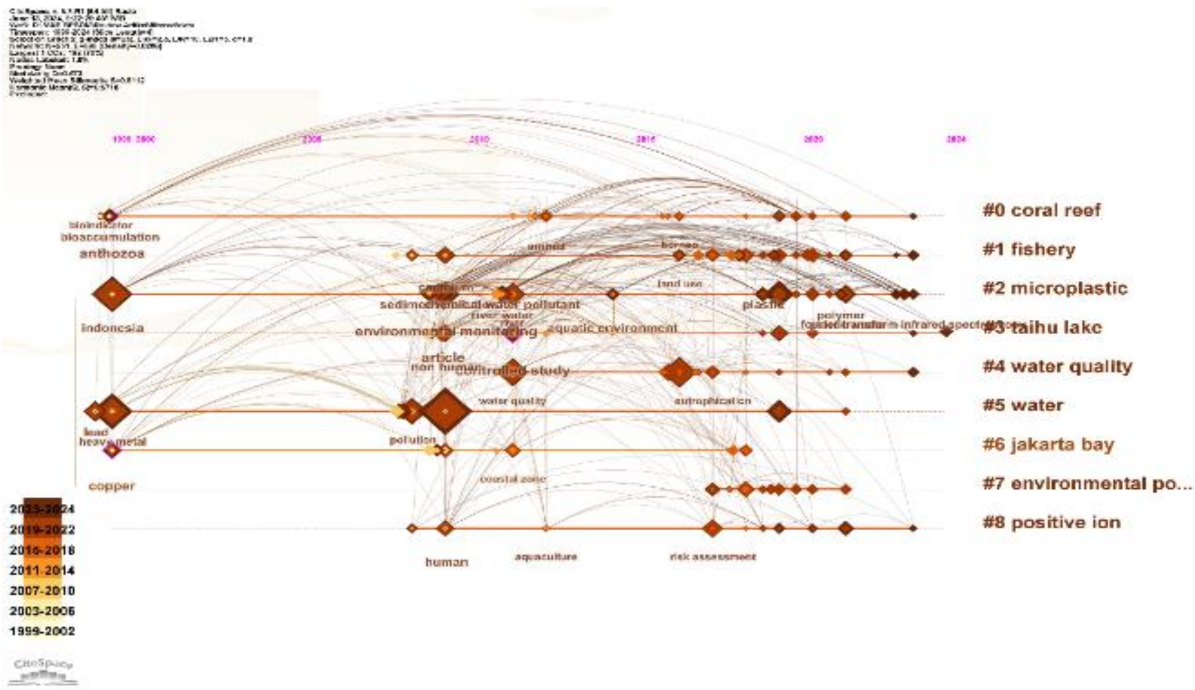

Figure 5. Cluster view of co-occurring author keywords

3.4 Mapping co-citations

Co-citation is assessed based on the centrality of research that significantly influences other studies, as shown by articles being frequently cited together. **Figure 6** presents the cluster view of the author co-citation network, displaying only the first author representing each article on the nodes. The visualization consists of 290 nodes over 7 slice years. Several irregularly shaped clusters with different colors are clearly visible. Lines connect authors within the same cluster and also link authors from different clusters, indicating studies co-cited by other researchers. There are 7 clusters: cluster #1 'aquaculture urban river', cluster #2 'benthic fauna', cluster #3 'seasonal variation', cluster #4 'heavy metal', cluster #5 'Dumai Sumatra Indonesia', cluster #6 'first evidence' and the last cluster, cluster #10 'global center'. Each cluster includes several highly cited members. Numerous articles on this topic have been organized into different clusters focusing on sediment contamination in Indonesia. One particular cluster, marked in purple and labeled Dumai Sumatera Indonesia, consists of 15 members and boasts a silhouette value of 0.986. The main topics in this cluster center around heavy metal contamination. The primary citing article for this cluster is by Amin.

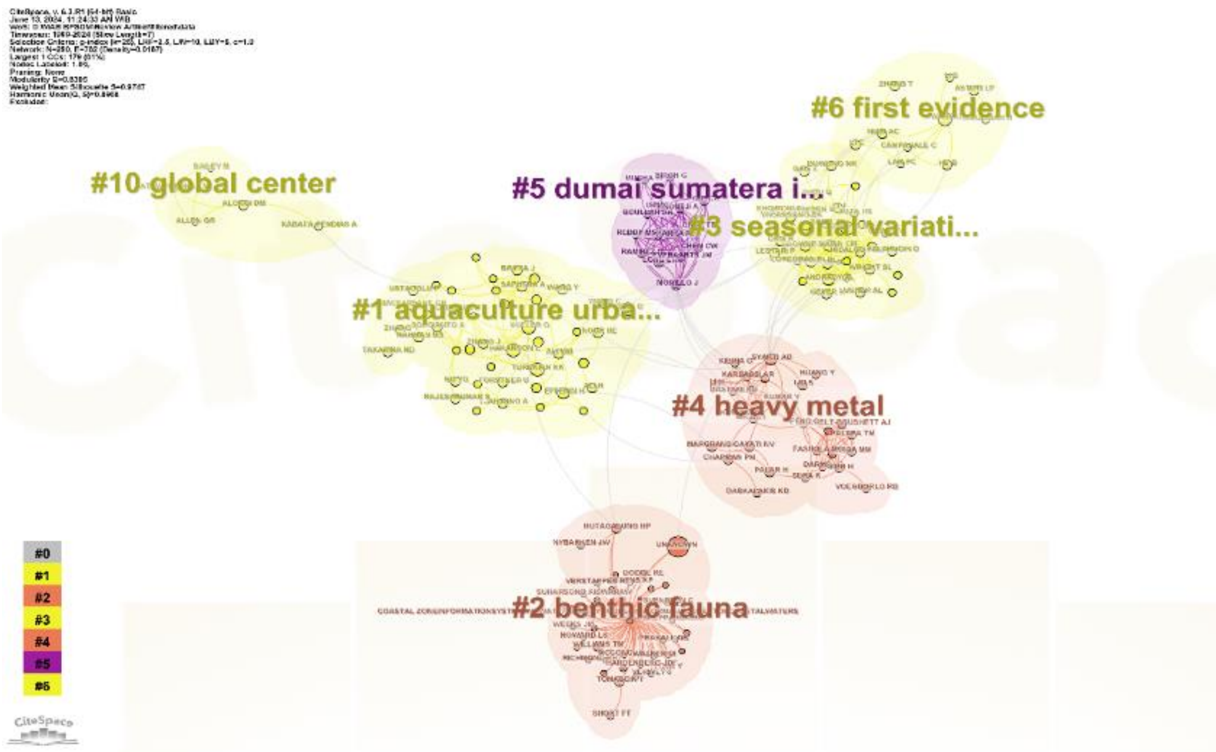

Figure 6. Cluster view of author co-citation network

The largest cluster, #1, comprises 46 members with a silhouette score of 0.956. The main cited article of this cluster is Rozirwan with the most cited members being Yona, Hakanson, and Muller. The top-ranked item by centrality is Hutagalung in cluster #2, with a centrality score of 0.21. The cluster view also displays linkages between clusters, signifying shared topics or interdisciplinary approaches. There are strong connections between clusters #1 and #4, suggesting a significant overlap between aquaculture urban rivers and heavy metal pollution research. Additionally, clusters #2 and 33 are interconnected, showing that studies on benthic fauna often involve seasonal variations.

3.5 Content Analysis

An investigation into heavy metal concentrations in coastal sediments was conducted in Dumai, Indonesia, a key maritime transportation route connecting the Malacca Strait to Sumatra. Sediment samples were collected from five distinct locations, each characterized by varying anthropogenic activities, using an Ekman Grab. The locations included an international port with industrial areas, a densely populated zone with cargo ports and an oil refinery, an agricultural area near a river estuary and cement factory, a commercial port, and a tourist resort exposed to the Malacca Strait. Analysis of heavy metals, including Cd, Cu, Pb, Zn, Fe, and Ni, revealed that locations near ports and densely populated areas exhibited the highest metal concentrations, particularly Pb and Zn, due to intense human and industrial activities. In contrast, areas farther from industrial influence showed significantly lower contamination. The findings underscore that anthropogenic and industrial sources largely drive heavy metal pollution in Dumai's coastal sediments (Amin et al., 2009). Research in the Java Sea, particularly around Kepulauan Seribu, examined microplastics in sediments from various environments, including beaches, sandy areas with and without seagrass, subtidal reef margins, and lagoon depths. Sampling in shallow waters and coastal regions was conducted using a cut-off syringe. The findings showed elevated microplastic concentrations at Semak Daun Beach, linked to tourism-related waste, and in the Panggang Island lagoon, where activities like boat painting contribute to pollution. Ineffective plastic waste management intensifies contamination, accumulating in marine organisms like coral reefs and zooplankton, disrupting ecosystems and the food chain. This poses risks to both marine life and human health through the ingestion of microplastics (Utami et al., 2021).

A study analyzing microplastic contamination in sediments was performed in the eastern waters of the Java Sea, specifically in Gresik, investigated microplastic contamination in sediments across five locations: a fishing hub, a mangrove area, a shrimp farm, the Bengawan Solo River estuary, and an offshore site 1 km from the estuary. The mangrove area showed the highest microplastic contamination due to tidal movements trapping waste among the roots, with plastic fragments and fibers being the most prevalent. Meanwhile, plastic films were most abundant in the fishing area. The study attributed the contamination primarily to anthropogenic activities and domestic waste (Yona et al., 2019). A survey on the Citarum River in West Java focused on detecting heavy metals and magnetic content in sediments. The 269 km-long river was divided into 21 sampling points, including its tributaries. Sampling took place during the rainy season in 2016 using a modified sediment trap with cotton cloth to capture suspended sediments for analysis. The study found that heavy metal concentrations, particularly Zn, increased downstream, especially in areas near industrial activities. Samples from tributaries were heavily influenced by industrial zones in Bandung. Locations with intense human activity tended to exhibit higher levels of magnetic content and heavy metal contamination (Sudarningsih et al., 2017).

An assessment of sediment contamination in coastal waters was conducted in Mimika Regency, Papua Province. Using a grab sampler, sediment samples were taken from six locations and analyzed following USEPA 1992 guidelines. The study found high Cu concentrations near Meoga and Puriri, likely due to mining activities around the Ajkwa River estuary, posing risks to marine organisms (Tanjung et al., 2019). Sediments act as major sites for heavy metal accumulation in the environment, with resuspension processes redistributing these contaminants into aquatic systems. This aligns with research conducted along the northern coast of Central Java, including Brebes, Tegal, Pekalongan, and Pemalang, which examined not only sediments but also water and shrimp. Heavy metal analysis using ICP-AES revealed that Pekalongan had higher cadmium levels due to industrial activities, while Brebes faced significant ecological risks from metal contamination. Tegal and Pemalang also experienced environmental challenges affecting shrimp health and production. Although most metal concentrations in shrimp were below permissible limits, elevated levels of lead (Pb), chromium (Cr), and cadmium (Cd) in regions like Pekalongan raised concerns about seafood safety, especially with regular consumption of shrimp from contaminated areas (Hidayati et al., 2020).

On the other hand, sediment sampling in Lake Tai, China, revealed a high abundance and diversity of antibiotic resistance genes (ARGs) embedded within the lake's sediments, significantly exceeding levels found in other global lakes. These sediments act as reservoirs for ARGs, driven by human and animal fecal pollution and high antibiotic usage in the surrounding areas. The presence of ARGs in sediments increases the risk of resistant pathogens spreading into the water column, potentially making infections harder to treat. Human exposure to these resistant bacteria can occur through contaminated water used for domestic purposes, agriculture, or consumption of aquatic products, posing serious public health risks. This highlights the critical role of sediment in the environmental spread of resistance and the urgent need for better wastewater and antibiotic management practices (Chen et al., 2019). There hasn't been much in-depth research on sediments in this area, which presents an opportunity for researchers to study sediments more closely. This gap in research could encourage scholars to explore sediments further. More studies on sediments could offer important insights for better pollution management and environmental protection.

4. Conclusion

To recapitulate, research on sediment contamination in Indonesia saw a significant increase starting in 2018. The selected documents are open access, with 63.28% being articles and the rest being conference papers. The most common subject area for this research is Environmental Science, with 111 documents. Indonesia leads with the most publications, totaling 167, and ranks highest in both citation counts (165) and centrality (1.28). The Department of Marine Science has the highest citation counts and degree, with 16 citation counts and a degree of 19, followed by the Department of Chemistry and the

Department of Aquatic Resources Management. The most frequently cited article is by Rozirwan, within the aquaculture urban river cluster. The highest frequency of cited articles was observed between 2011 and 2014, with the article by Yona having the most citations at 5. The top three most frequent keywords are sediment, Indonesia, and heavy metal. Leveraging sediment contamination trends, future research could delve into the effects on ecosystems and human health, and propose mitigation strategies. Integrating these aspects into one comprehensive study would yield a compelling and densely informative publication. Indonesia has undertaken extensive research on sediment contamination, revealing significant impacts of heavy metals, microplastics, and antibiotic-resistance genes due to industrial and anthropogenic activities. Studies in Dumai, the Java Sea, and Citarum River emphasize the need for improved pollution control and waste management, while findings in Central Java and Mimika highlight ecological risks to marine life and seafood safety. Research in Lake Tai, China underscores sediments as reservoirs for antibiotic resistance genes, raising global concerns about resistant pathogen spread and the need for stricter environmental interventions.

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