

A Bibliometric Analysis of the Southeast Asia's Growing Contribution to Cr(VI) Adsorption-Based Wastewater Treatment Research

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ABSTRACT

Hexavalent chromium (Cr(VI)) contamination remains a critical environmental concern due to its toxicity, persistence, and mobility in aquatic systems, prompting extensive research into effective treatment technologies, particularly adsorption. Despite growing global interest, a comprehensive understanding of Southeast Asia's contribution and evolving influence in this research domain remains limited. This study addresses this gap by conducting a bibliometric analysis to evaluate publication trends, influential works, collaborative networks, and thematic development related to Cr(VI) treatment research, with an emphasis on Southeast Asia. Bibliographic data were retrieved from the Scopus database using a structured search strategy and subsequently refined through predefined inclusion criteria. Data cleaning and standardization were performed using OpenRefine, while descriptive performance indicators were generated through the Scopus Analyzer. Network visualization and clustering analyses were conducted using VOSviewer to map co-authorship, co-citation, and keyword co-occurrence patterns. A total of 659 final-stage journal articles published between 2020 and February 2026 were included in the analysis. The results indicate a consistent increase in annual publication output, with Malaysia, Indonesia, and Vietnam emerging as leading contributors within the region. Keyword mapping highlights adsorption, wastewater treatment, heavy metals, kinetics, and biochar as dominant research themes, reflecting a strong emphasis on material innovation and mechanistic evaluation. Collaborative networks reveal increasing regional integration alongside expanding international linkages. Overall, the findings demonstrate a measurable rise in Southeast Asia's scientific visibility and impact in Cr(VI) treatment research, underscoring the strategic importance of bibliometric assessment for understanding regional research dynamics and guiding future scientific development. The findings contribute to Sustainable Development Goal (SDG) 6: Clean Water and Sanitation by providing bibliometric evidence to inform future research and policy development on sustainable wastewater treatment technologies.

Keywords: Hexavalent chromium, Cr(VI), Adsorption, Heavy Metal, Bibliometric Analysis.

1. INTRODUCTION

Hexavalent chromium (Cr(VI)) is a highly toxic and carcinogenic heavy metal commonly found in industrial wastewater, posing significant environmental and public health risks. The contamination of water bodies with Cr(VI) is primarily due to effluents from industries such as tanneries, textiles, mining, painting, printing, and medicine [1, 2]. The Environmental Protection Agency (EPA) has classified Cr(VI) as a priority pollutant, necessitating stringent regulations for its removal from wastewater [3, 4]. The persistence and non-biodegradable nature of Cr(VI)

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exacerbate its detrimental effects on ecosystems, leading to severe health issues, including dermatitis, allergic reactions, skin ulcerations, bronchial carcinoma, asthma, and gastroenteritis [5]. Therefore, effective treatment methods are crucial to mitigate the adverse impacts of Cr(VI) contamination.

Adsorption has emerged as a promising technique for removing Cr(VI) from wastewater due to its high efficiency, low cost, and minimal generation of chemical sludge [2, 6]. The adsorption process involves the binding of Cr(VI) ions to the surfaces of various adsorbents through mechanisms such as ion exchange, surface complexation, and electrostatic interactions [5,7]. Recent research has focused on the development and optimization of diverse adsorbents, including bio-based substances, metal oxides, nanomaterials, and agricultural wastes, to enhance the adsorption capacity and specificity for Cr(VI) removal [3, 5, 8]. Key parameters influencing the adsorption efficiency include pH, temperature, initial Cr(VI) concentration, and adsorbent dosage [9-11]. For instance, studies have shown that Cr(VI) adsorption is highly dependent on solution pH, with optimal removal typically occurring in acidic conditions [2, 7, 11]. Recent advancements in adsorption technology have introduced novel adsorbents with improved performance and potential for industrial applications. For example, zirconium-based adsorbents have demonstrated rapid responsiveness and high adsorption capacity, achieving up to 97.9 mg/g of Cr(VI) removal within 30 minutes [4]. Similarly, modified agricultural wastes such as date stones and palm fibre have shown promising results, with adsorption capacities of 16 and 6 mg/g, respectively [3]. The use of nanomaterials, such as functionalized chitosan and zeolite-A crystals, has further enhanced the adsorption efficiency due to their large specific surface area and high chemical stability [8, 12]. Additionally, the development of artificial neural network (ANN) models and computational methods has facilitated the prediction and optimization of adsorption processes, contributing to the scalability and practical application of these technologies [4, 13].

Southeast Asia represents one of the fastest-growing industrial regions globally, with substantial expansion in manufacturing sectors such as electroplating, textile production, mining, metal finishing, and chemical processing. These industries are recognised as major sources of chromium-containing wastewater, creating increasing environmental concerns and regulatory challenges. Consequently, considerable research efforts have been directed towards developing sustainable Cr(VI) remediation technologies, making Southeast Asia an appropriate and timely region for bibliometric investigation. Figure 1 illustrates three primary dimensions of Cr(VI) wastewater treatment: environmental impact, process optimization, and adsorption-based approaches. The environmental dimension emphasizes sustainability, pollution control, and regulatory compliance alongside removal efficiency. Optimization leverages machine learning and computational tools to enhance operational performance and minimize energy costs. Meanwhile, adsorption remains the central technical pathway, increasingly utilizing advanced nanomaterials, kinetic studies, and surface complexation modelling to improve selectivity and capacity. Ultimately, the concept map demonstrates that sustainable Cr(VI) remediation requires a multidisciplinary framework that integrates material innovation, data-driven optimization, and ecological management to achieve both technical efficiency and long-term environmental protection.

In summary, the adsorption technique for Cr(VI) removal from wastewater has gained significant attention due to its effectiveness, cost-efficiency, and environmental benefits. The continuous research and development of novel adsorbents and optimization of adsorption parameters are crucial for advancing this field and addressing the challenges posed by Cr(VI) contamination. Future studies should focus on the scalability of these technologies, the regeneration and reusability of adsorbents, and the integration of adsorption processes with other treatment methods to achieve comprehensive and sustainable wastewater management solutions.

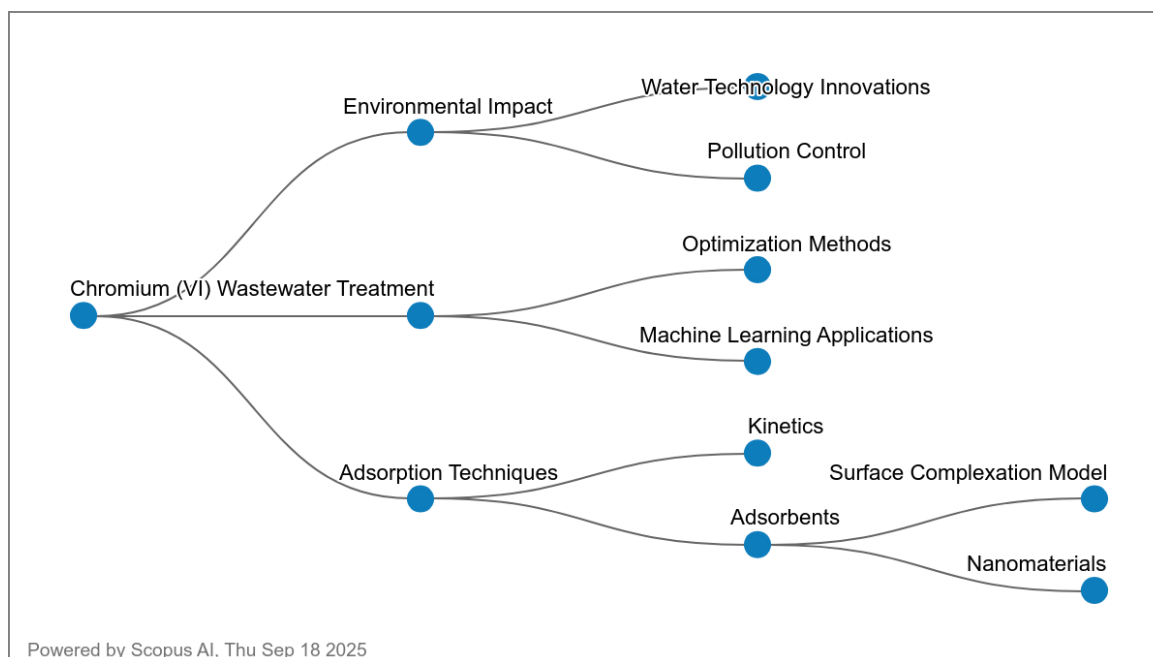


Figure 1: Concept map for Cr(VI) wastewater treatment.

1.1 Research Question

- RQ1: How has the research on Cr(VI) wastewater treatment using adsorption techniques evolved over time based on publication year in Southeast Asia?
- RQ2: Which articles in this research area have received the highest number of citations?
- RQ3: Which Southeast Asia countries contribute the most publications to this field?
- RQ4: What are the most frequently used keywords in the literature related to this study?
- RQ5: How do countries collaborate in co-authorship within this research domain?

2. METHODOLOGY

Bibliometrics involves gathering, organizing, and analysing bibliographic data from scientific publications [14-16]. Beyond basic statistics, such as identifying publishing journals, publication years, and leading authors [17], bibliometrics includes more sophisticated techniques like document co-citation analysis. Conducting a successful literature review requires a careful, iterative process to select suitable keywords, search the literature, and perform an in-depth analysis. This approach helps to compile a comprehensive bibliography and achieve reliable results [18]. With this in mind, the study focused on high-impact publications, as they provide meaningful insights into the theoretical frameworks that shape the research field. To ensure data accuracy, Scopus served as the primary source for data collection [19-21]. Additionally, to maintain quality, the study only considered articles published in peer-reviewed academic journals, deliberately excluding books and lecture notes [22]. Using the Scopus database, which is known for its broad coverage, publications were collected from 2020 through February 2026 for further analysis."

2.1 Data Search Strategy

A systematic screening procedure was conducted to establish appropriate search terms for article identification. The process began with a query in the Scopus database using the online TITLE-ABS-KEY function with the following keywords: ("Chromium" OR "Hexavalent chromium" OR "chromium (VI)" OR "Cr" OR "Cr (VI)" OR "Cr VI" OR "Chromium remediation" OR "Chromium ions") AND "adsorption". This initial search generated 30,185 records. The results were then

filtered to retain only research articles written in English and published as journal papers. Publications associated with countries in Southeast Asia were included to refine the geographical scope, where author affiliations were limited to Southeast Asian countries, including Malaysia, Indonesia, Singapore, Thailand, Vietnam, the Philippines, Brunei Darussalam, Cambodia, Lao PDR, and Myanmar. After this refinement stage, 1,098 articles remained and were considered suitable for bibliometric evaluation.

Subsequently, an additional limitation was applied to include only documents published from 2020 until February 2026 and classified as final publications. The selected time window (2020–February 2026) was intentionally chosen to capture the most recent phase of research characterised by rapid advancements in sustainable adsorbent materials, nanotechnology, machine learning-assisted optimisation, and increasing environmental regulations. The study therefore aims to evaluate contemporary research dynamics rather than long-term historical evolution. This step reduced the dataset to 659 articles. As of February 2026, all relevant Scopus-indexed publications addressing Cr(VI) and adsorption that met the defined criteria were incorporated. Since the resulting number of documents was considered manageable, no additional exclusion parameters were introduced, and the entire dataset was retained for further analysis. The details of the data search strategy are tabulated in Table 1.

Table 1: Data searching strategy.

Criteria	Inclusion	Exclusion	Result
Search string (Abstract / Title / Keyword)	("Chromium" OR "Hexavalent chromium" OR "chromium (VI)" OR "Cr" OR "Cr (VI)" OR "Cr VI" OR "Chromium remediation" OR "Chromium ions") AND "adsorption"	-	30,185
Country/territory	Southeast Asia	Besides Southeast Asia	1,398
Language	English	Non-English	1,395
Literature type	Journal (Article)	Conference, Book, Review	1,098
Timeline	2020 – February 2026	< 2020	670
Publication Stage	Final	In Press	659

Date of Access: February 2026

2.2 Data Analysis

Prior to bibliometric analysis, the retrieved records were processed using OpenRefine (Version 3.9.3). Data cleaning involved duplicate verification, correction of inconsistent author keywords, merging synonymous terms (e.g., "Cr(VI)", "Chromium (VI)", and "Hexavalent chromium"), standardisation of country names, and removal of typographical inconsistencies. This process ensured greater consistency and improved the accuracy of subsequent network visualisation analyses.

Subsequently, VOSviewer is a bibliometric analysis software created by Nees Jan van Eck and Ludo Waltman at Leiden University in the Netherlands [23, 24]. The program is frequently applied for mapping and examining scientific publications. It is designed to construct network visualizations, group related elements into clusters, and produce density representations. Through these functions, relationships such as co-authorship, co-citation, and keyword co-occurrence can be systematically explored [25, 26]. The interface is relatively simple, which supports efficient handling of extensive bibliographic records. Regular updates and compatibility with multiple bibliometric data formats further enhance its applicability. In addition, the software enables the calculation of relevant indicators and the adjustment of visualization parameters, which assist scholars in interpreting complex research structures across different subject areas. A notable capability of VOSviewer is its ability to transform large-scale bibliometric data into clear graphical maps. The software applies VOS clustering and mapping techniques to position

items within a low dimensional space, where the distance between two elements represents the degree of relatedness [24]. In this aspect, the approach is conceptually comparable to Multidimensional Scaling (MDS) methods [27]. However, rather than relying solely on similarity indices such as cosine or Jaccard measures, VOSviewer uses association strength normalization to better evaluate co-occurrence frequencies [28]. For the present analysis, bibliographic records containing publication year, title, authors, journal source, citation data, and keywords were retrieved from the Scopus database in PlainText format, covering the period from 2020 until February 2026, and processed using VOSviewer version 1.6.19. Diverging from MDS, which primarily engages in the computation of similarity metrics like cosine and Jaccard indices, VOS utilizes a more fitting method for normalizing co-occurrence frequencies, such as the association strength (AS_{ij}), and it is calculated as [28]:

$$AS_{ij} = \frac{c_{ij}}{w_i w_j} \quad (1)$$

Which is “proportional to the ratio between on the one hand the observed number of cooccurrences of i and j and on the other hand the expected number of co-occurrences of i and j under the assumption that co-occurrences of i and j are statistically independent” [28].

3. RESULTS AND DISCUSSION

3.1 Model and Data

The distribution of publications from 2020 to 2026 indicates a general upward trajectory in research related to Cr(VI), as illustrated in Figure 2. It should be noted that the publication count for 2026 represents records indexed only until February 2026 and therefore, should not be directly compared with complete annual publication data. In 2020, a total of 73 articles were recorded, representing 11.08 percent of the dataset and reflecting the baseline level at the beginning of the observed period. A substantial increase occurred in 2021 and 2022, with 106 and 109 publications, accounting for 16.08 percent and 16.54 percent, respectively. This pattern suggests growing academic and scientific attention to Cr(VI) wastewater treatment in Southeast Asia, particularly toward adsorption-based approaches. The consistent rise during these years may be associated with heightened environmental awareness and stricter regulatory requirements concerning heavy metal contamination.

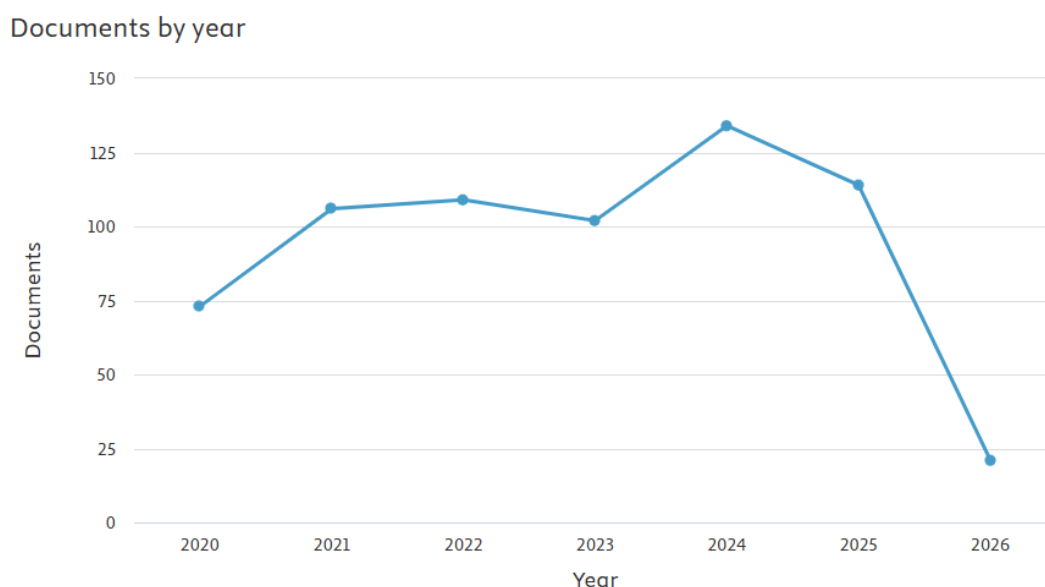


Figure 2: Publication trend for Cr (VI) wastewater treatment by years.

The upward trend continued in 2023 and peaked in 2024. In 2023, 102 publications were documented, contributing 15.48 percent of the total output. Although slightly lower than the previous year, the figure remained comparatively high. The highest number of publications was observed in 2024, with 134 articles corresponding to 20.33 percent. This peak indicates that research activity intensified significantly, possibly due to advancements in novel adsorbent materials, nanotechnology applications, and process optimization strategies. The data reflect strong and sustained research interest during the mid-period of the analysis.

In 2025, the number of publications declined slightly to 114, representing 17.30 percent, yet remained at a relatively elevated level compared to earlier years. For 2026, 21 publications were recorded, accounting for 3.19 percent. The lower percentage for 2026 is likely due to incomplete data coverage, as the year may not have concluded by the time of data extraction. Overall, the findings demonstrate a clear expansion of research output over time, with a notable surge between 2021 and 2024, followed by stable yet substantial scholarly engagement in subsequent years. Table 2 presents information on this research trend in Southeast Asia.

Table 2: Publication trend on Cr (VI) in Southeast Asia.

Year	Number of Publications	Percentage (%)
2026	21	3.19
2025	114	17.30
2024	134	20.33
2023	102	15.48
2022	109	16.54
2021	106	16.08
2020	73	11.08
Total	659	100.00

3.2 Top Cited Articles in Cr (VI) Adsorption Research

Table 3 presents the citation profile of the ten most influential publications, indicating strong scholarly attention toward adsorption-based remediation of heavy metals and related contaminants. The most highly cited article is authored by Sekar et al. (2021) in the *Journal of Hazardous Materials*, receiving 360 citations. This study examines microplastics as vectors for heavy metals, highlighting the interconnected nature of emerging pollutants and metal contamination. Nizam et al. (2021) in *Scientific Reports* follow closely with 348 citations, focusing on biomass-derived activated carbon for dye removal. Yu et al. (2021) in *Environmental Pollution* obtained 279 citations, emphasizing equilibrium and kinetic modelling in biochar-based adsorption systems. These highly cited works demonstrate that research impact is often associated with comprehensive experimental design combined with environmental relevance.

Several influential contributions are concentrated in high-impact journals such as *Chemosphere* and *Chemical Engineering Journal*. Hoang et al. (2022) compiled 255 citations in a review of biomass-derived carbon nanotubes for heavy metal removal, reflecting substantial interest in advanced carbon materials. Neolaka et al. (2020) in the *Journal of Materials Research and Technology* reported 237 citations on graphene oxide magnetic composites targeting Cr(VI). Chen et al. (2022) in *Chemical Engineering Journal* reported 189 citations for a multifunctional hydrogel system for simultaneous detection and adsorption of Cu(II) and Cr(VI). These studies illustrate the importance of novel composite materials and multifunctional adsorbents in driving citation performance.

Table 3: Top 10 most cited authors in Southeast Asia in Cr (VI) wastewater treatment.

Authors	Title	Year	Source title	Cited by
Sekar et al. [29]	Hazardous microplastic characteristics and its role as a vector of heavy metals in groundwater and surface water of coastal South India	2021	Journal of Hazardous Materials	360
Nizam et al. [30]	The removal of anionic and cationic dyes from an aqueous solution using biomass-based activated carbon	2021	Scientific Reports	348
Yu et al. [31]	Adsorptive removal of cationic methylene blue and anionic Congo red dyes using wet-torrefied microalgal biochar: Equilibrium, kinetic and mechanism modeling	2021	Environmental Pollution	279
Hoang et al. [32]	Heavy metal removal by biomass-derived carbon nanotubes as a greener environmental remediation: A comprehensive review	2022	Chemosphere	255
Neolaka et al. [33]	The adsorption of Cr(VI) from water samples using graphene oxide-magnetic (GO-Fe ₃ O ₄) synthesized from natural cellulose-based graphite (kusambi wood or <i>Schleichera oleosa</i>): Study of kinetics, isotherms and thermodynamics	2020	Journal of Materials Research and Technology	237
Chen et al. [34]	Fluorescent carbon dots crosslinked cellulose Nanofibril/Chitosan interpenetrating hydrogel system for sensitive detection and efficient adsorption of Cu (II) and Cr (VI)	2022	Chemical Engineering Journal	189
Nguyen et al. [35]	Evaluate the role of biochar during the organic waste composting process: A critical review	2022	Chemosphere	176
Neolaka et al. [36]	A Cr(VI)-imprinted-poly(4-VP-co-EGDMA) sorbent prepared using precipitation polymerization and its application for selective adsorptive removal and solid phase extraction of Cr(VI) ions from electroplating industrial wastewater	2020	Reactive and Functional Polymers	163
Neolaka et al. [37]	Evaluation of magnetic material IIP@GO-Fe ₃ O ₄ based on Kesambi wood (<i>Schleichera oleosa</i>) as a potential adsorbent for the removal of Cr(VI) from aqueous solutions	2021	Reactive and Functional Polymers	162
Krishnamoorthy et al. [38]	Biosorption performance of date palm empty fruit bunch wastes for toxic hexavalent chromium removal	2020	Environmental Research	160

Recurring authorship by Neolaka and collaborators appears across multiple entries, including publications in *Reactive and Functional Polymers* in 2020 and 2021, each exceeding 160 citations. This pattern suggests a sustained contribution to the development of selective sorbents and magnetically imprinted polymers for Cr(VI) removal. Additional highly cited works, such as Krishnamoorthy et al. (2020) in *Environmental Research*, further confirm the relevance of low-cost biosorbents derived from agricultural waste. Overall, the citation distribution reveals that studies integrating material innovation, mechanistic evaluation, and practical environmental applications tend to receive higher academic recognition in this research domain.

Collectively, the highly cited studies demonstrate several common characteristics that contribute to their scientific impact. First, most publications introduce innovative adsorbent materials that achieve high adsorption capacity while maintaining environmental sustainability. Second, many studies integrate comprehensive adsorption mechanisms, kinetic modelling, isotherm analysis, and thermodynamic evaluation, providing stronger scientific evidence for practical implementation. Finally, increasing attention towards biomass-derived adsorbents,

nanomaterials, and multifunctional composite materials reflects the global transition towards sustainable and circular wastewater treatment technologies.

3.3 Leading Southeast Asia Country Based on the Number of Publications

The distribution of publications among Southeast Asian countries from 2020 to February 2026 indicates a clear concentration of research output within several leading nations, as illustrated in Figure 3. Malaysia records the highest number of publications with 200 documents, followed by Indonesia with 166 and Vietnam with 157. These three countries collectively account for a substantial proportion of the regional scientific contribution in Cr(VI) related adsorption research. The strong performance may be associated with expanding higher education systems, increased governmental funding for environmental research, and growing concern regarding industrial wastewater management. The data suggest that these countries serve as primary research hubs in Southeast Asia.

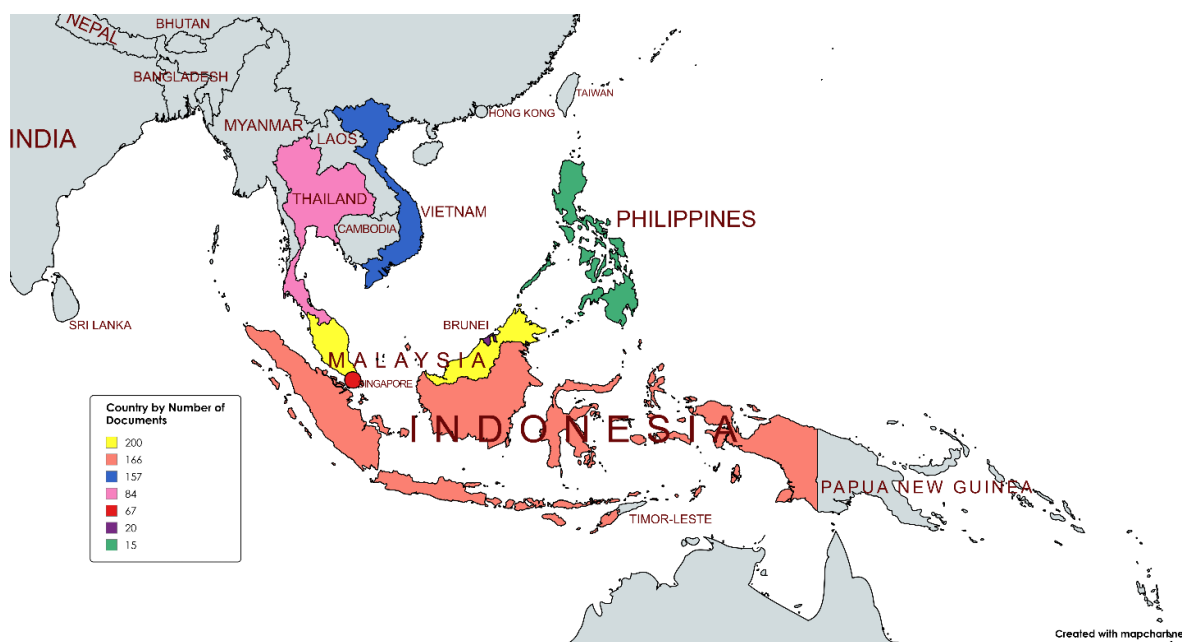


Figure 3: Most influential Southeast Asia countries by documents.

Thailand and Singapore demonstrate moderate yet significant levels of productivity, with 84 and 67 publications, respectively. Although the absolute number is lower compared to Malaysia, Indonesia, and Vietnam, the output remains notable considering differences in population size, research infrastructure, and national funding priorities. Singapore, in particular, is recognized for its advanced research ecosystem and international collaboration networks, which may enhance citation impact despite a comparatively smaller publication volume. Thailand's contribution reflects continued engagement in environmental remediation studies, especially in water quality and materials development.

In contrast, Brunei Darussalam and the Philippines exhibit relatively limited publication counts, with 20 and 15 documents, respectively. This lower output may reflect smaller research communities or limited specialization in heavy metal adsorption studies. Overall, the regional pattern demonstrates uneven but progressively expanding research activity across Southeast Asia. The prominence of Malaysia, Indonesia, and Vietnam highlights their central role in advancing knowledge of Cr(VI) wastewater treatment, while other nations present potential for future growth through strengthened research investment and regional collaboration. Malaysia's leading publication output may be attributed to several complementary factors, including sustained government investment in higher education and research, increasing environmental

surface methodology” signals the growing adoption of statistical optimization tools and multivariate experimental design. Collectively, these methodological terms suggest that the field is characterized by quantitative standardization, reproducibility, and analytical sophistication, which are hallmarks of consolidation and scientific depth.

Material innovation emerges as a third strategic axis within the bibliometric structure. Traditional adsorbents such as “Activated carbon adsorption” and “Chitosan” coexist with advanced materials including “Biochar,” “Metal-organic framework,” “Layered double hydroxide,” “Nanocomposites,” and “Graphene oxide.” The relatively high link strengths associated with biochar and metal-organic frameworks indicate expanding interdisciplinary integration and strong cross-linkages with pollutant and modelling keywords. This trend suggests a transition toward engineered, high-surface-area, and chemically tuneable materials designed for enhanced selectivity and capacity. The concurrent visibility of dye models such as “Methylene blue” alongside heavy metal species reinforces the dual emphasis on organic and inorganic contaminant removal. Overall, the network topology reflects a field that is application-oriented, methodologically rigorous, and increasingly driven by advanced material design to address complex wastewater challenges.

Table 4: Distribution of the most common keywords’ co-occurrence.

Keyword	Occurrences	Total link strength
Adsorption	234	475
Wastewater treatment	64	127
Congo red	52	117
Cr (vi)	51	103
Heavy metals	49	91
Kinetics	27	75
Chromium	36	74
Hexavalent chromium	35	65
Isotherm	22	61
Biochar	22	56
Metal-organic framework	26	56
Layered double hydroxide	21	50
Chitosan	24	48
Thermodynamics	17	47
Kinetic model	15	37
Nanocomposites	12	35
Response surface methodology	15	34
Graphene oxide	17	32
Methylene blue	14	32
Activated carbon adsorption	17	29

3.5 Global Co-Authorship Networks

The VOSviewer network reveals several collaboration clusters distinguished by different colours, representing groups of countries with relatively stronger research partnerships. Malaysia occupies a central position and has the highest total link strength, indicating extensive collaboration with both ASEAN partners and international research institutions. The network further suggests that collaborations extend beyond intra-ASEAN partnerships to include China, India, Saudi Arabia, Australia, Japan, and South Korea, highlighting Southeast Asia’s growing integration into the global research ecosystem.

The co-authorship landscape reveals a pronounced concentration of research productivity and collaborative intensity within Asia, with Malaysia leading in documents (199), citations (5130), and total link strength (288) as presented in Figure 5 and Table 5. This dominant position indicates not only high scholarly output but also extensive international connectivity, positioning Malaysia as a central hub in the global knowledge network. Vietnam and Indonesia follow with substantial document counts of 157 and 166, respectively, although their total link strengths of 116 and 112 suggest comparatively moderate integration within broader transnational collaborations. In contrast, China and India demonstrate a more balanced profile between productivity and connectivity. China records 87 documents and a strong link strength of 181, while India, with 74 documents, achieves 3213 citations and a link strength of 172. These figures indicate that, despite lower publication counts relative to Malaysia, both countries exert considerable influence through impactful and well-networked research partnerships.

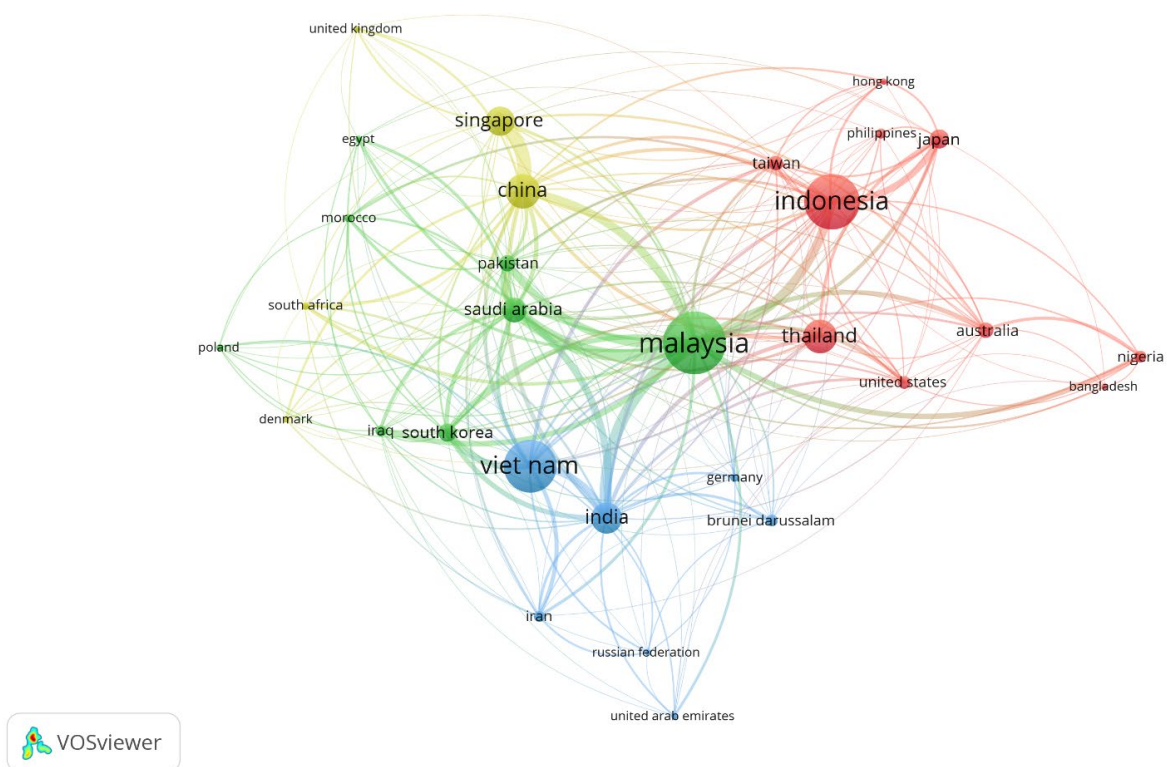


Figure 5: Network visualisation map of co-authorship by countries' collaboration.

Middle Eastern and East Asian countries constitute a secondary but strategically important cluster of collaboration. Saudi Arabia exhibits a high total link strength of 159 across its 52 documents, suggesting a deliberate emphasis on international partnerships to enhance network centrality. South Korea, Singapore, Japan, Thailand, and Taiwan display moderate productivity with varying citation impacts, reflecting diversified but less centralized collaboration patterns. Notably, Taiwan achieves 1147 citations from only 25 documents, indicating a high average citation impact and potentially strong participation in influential multinational projects. The relatively strong link strengths of South Korea and Singapore further point to their integration within regional research circuits, reinforcing Asia's structural prominence in the collaborative architecture of this domain.

Western and emerging economies contribute to the network with more modest yet strategically significant roles. Australia demonstrates a balanced profile with 28 documents, 1342 citations, and a link strength of 53, indicating sustained engagement in international partnerships. The United States, despite its traditionally dominant position in global science, records comparatively

limited output and link strength in this specific domain, suggesting that leadership is regionally concentrated elsewhere. Countries such as Iran, Pakistan, Nigeria, South Africa, Morocco, Egypt, and Iraq show emerging participation with lower document counts but meaningful connectivity values, reflecting gradual integration into the global research system. Overall, the collaboration network is characterized by strong Asian leadership, expanding engagement in the Middle East, and a distributed pattern of emerging contributors, collectively illustrating a multipolar and regionally anchored structure of scientific cooperation.

Table 5: Co-authorship by countries' collaboration.

Country	Documents	Citations	Total link strength
Malaysia	199	5130	288
China	87	2745	181
India	74	3213	172
Saudi Arabia	52	1383	159
Vietnam	157	4758	116
Indonesia	166	2381	112
South Korea	35	1146	90
Pakistan	31	954	82
Singapore	67	1852	80
Japan	37	737	63
Thailand	84	1310	59
Taiwan	25	1147	58
Australia	28	1342	53
Iraq	18	342	50
United States	22	766	49
Iran	18	930	43
Morocco	11	243	36
Nigeria	19	625	34
South Africa	10	240	34
Egypt	8	241	29

4. CONCLUSION

This study set out to examine the growing influence of Southeast Asia in Cr(VI) wastewater treatment research, with particular emphasis on adsorption-based approaches. The bibliometric assessment was designed to address several core questions, including the temporal evolution of publications, the identification of highly cited works, the leading contributing countries, the dominant keywords, and patterns of international collaboration. By systematically analysing peer-reviewed journal articles indexed in Scopus between 2020 and February 2026, the study aimed to provide a structured overview of research development and to clarify the regional position of Southeast Asia within the broader global knowledge landscape on Cr (VI) remediation.

The findings reveal a clear upward trajectory in publication output, with research activity intensifying significantly after 2020 and peaking around 2024. Citation analysis indicates that influential studies are commonly associated with advanced adsorbent materials, mechanistic modelling, and practical environmental applications. Malaysia, Indonesia, and Vietnam emerge as the principal contributors within Southeast Asia, collectively accounting for a substantial share of regional publications and demonstrating strong engagement in collaborative networks.

Keyword co-occurrence mapping highlights adsorption as the central conceptual pillar, closely connected to wastewater treatment, heavy metals, kinetics, isotherm modelling, and emerging materials such as biochar, metal organic frameworks, and nanocomposites. The co-authorship network further illustrates that Southeast Asia is not operating in isolation but is embedded within a wider Asian centred collaboration structure, with meaningful linkages to East Asia, the Middle East, and selected Western countries.

Several limitations should be acknowledged. First, this study relied exclusively on the Scopus database, which may omit relevant publications indexed in Web of Science (WoS), Dimensions, or other bibliographic databases. Second, only English-language journal articles were included, potentially excluding valuable regional publications published in other languages. Third, conference proceedings, review articles, and book chapters were excluded to maintain consistency in publication quality. Fourth, citation-based indicators may favour older publications due to citation accumulation over time, introducing citation time bias. Finally, bibliometric databases are continuously updated, meaning publication and citation counts may change after the data collection period.

This study contributes to the field by offering an integrated regional perspective that clarifies how Southeast Asia has strengthened its scientific presence in research on Cr(VI) treatment. The results provide evidence of increasing methodological sophistication, material innovation, and cross-border collaboration. From a practical standpoint, the documented growth signals expanding research capacity that may support technological transfer, pilot-scale implementation, and policy-informed wastewater management strategies across the region. Nevertheless, the analysis is limited to a single database and a defined time window, which may exclude relevant publications indexed elsewhere or published prior to 2020. Future investigations may incorporate multiple databases, extend the temporal coverage, and conduct comparative assessments with other global regions to obtain a more comprehensive understanding. In conclusion, bibliometric evaluation is a valuable tool for tracking scientific development and identifying strategic research directions. The observed rise in Southeast Asia's role in Cr(VI) adsorption research reflects not only quantitative expansion but also qualitative advancement, indicating a progressively influential role in addressing heavy metal contamination challenges.

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