Moroccan Journal of Chemistry
ISSN : 2351-812X

Mor. J. Chem., 2023, Volume 11, Issue 01, Page 01-19
https://revues.imist.ma/index.php/morjchem

Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis

Asep Bayu Dani Nandiyanto[1,*], Risti Ragadhita[1], Dwi Novia Al Husaeni[1], Willy Cahya Nugraha[2]

[1] *Universitas Pendidikan Indonesia, Jl. Setiabudi No. 229, Bandung 40154, Indonesia*
[2] *Research Center for Environmental and Clean Technology, Badan Riset dan Inovasi Nasional, Bandung, Indonesia*
**Corresponding author, Email address: nandiyanto@upi.edu*

Received *02 Nov 2022,*
Revised *20 Dec 2022,*
Accepted *23 Dec 2022*

Citation*: Nandiyanto A.B.D., ragadhita R., Al Husaeni D. N. Nugraha W.C. (2023) Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis, Mor. J. Chem., 14(1), 01-19. Doi: 10.48317/IMIST.PRSM/morjchem-v%vi%i.36576*

Abstract: This study was conducted to analyze scientific trends about mercury-related applications in artisanal and small-scale gold mining (ASGM) through a bibliometric study on the Google Scholar database using VOSviewer. To support the analysis, this study was also completed with a literature review of ASGM. Based on the results of data using the keywords of "mercury", "gold mining", "particle technology", and "adsorption" using Publish or Perish from 2018 to 2022, 988 articles were detected and selected from Google Scholar. The results of searching data for the last 5 years showed that publications on related keywords increased in 2020 to 239 publications and decreased in 2021 and 2022 to 210 and 121, respectively. To support the analysis, three visualization forms in the data mapping analysis were completed: network visualization, overlay visualization, and density visualization. The results of this study are expected to assist researchers in recognizing global research trends regarding the proposed keywords that can be used as a reference in conducting further research.

Keywords: Adsorption, Artisanal small-scale gold mining (ASGM), Environment, Mercury, Science mapping, Scientometrics, Wastewater treatment

1. Introduction

Mercury (known as Hg) is one of the top 10 highly toxic chemicals that are ubiquitous in water, air, soil, and other parts of the environment (Carravieri *et al*., 2017; Palathoti *et al*., 2022). Mercury consists of three forms namely elemental, organic mercury, and inorganic mercury, and all these forms cause toxic effects on the environment when they are exposed (Yang *et al*., 2020). For example, mercury as a gaseous element (Hg^0) can freely travel long distances in the atmosphere which has harmful effects. Various forms of mercury that are exposed to the environment can enter the human body through different routes and different concentrations. The various forms of mercury have different health effects depending on the exposure time, the magnitude of exposure, and the mercury type (Wilhelm and Bloom, 2000). Moreover, in terrestrial and aquatic environments, mercury forms oxidized elements (Hg^{2+}) and binds to particulate species in the environment (Kwon *et al*., 2020).

Mercury released into the environment can come from natural and anthropogenic sources. However, most of the mercury released into the environment is from anthropogenic sources because of human

activities (Yang *et al*., 2020). Some examples of anthropogenic activities are burning fossil fuels, smelting metals, burning waste, and producing cement (Diaz *et al*., 2020). One of the main sources of anthropogenic emissions in the environment is the activity of the gold mining sector known as artisanal and small-scale gold mining (ASGM) (Moody *et al*., 2020). Gold mining is one of the most important industries in the world. ASGM mining typically uses elemental liquid mercury (Hg^0) to combine gold from rock, which is crushed into sediments, separating them from the gangue minerals, and concentrating them into solid amalgams. However, because of this process, the whole ore incorporation process produces tailings waste due to the release of mercury and contaminating the environment (Esdaile and Chalker, 2018; Zolnikov and Ortiz, 2018). For example, mercury from mining activities discharged into the environment can turn into organic mercury species (methylmercury/Me-Hg). In addition, in the ASGM process, during the amalgamation process, amalgam usually contains about 40-60% of Hg^0. When Hg^0 is burned, it will be directly discharged into the atmosphere.

Some cases due to mercury poisoning include a phenomenal case that occurred in Japan in 1950, namely the Minamata case where the poisoning material occurred in residents who consumed seafood from the bay. The main reason is due to the presence of Me-Hg that is being released into the bay (Zuas *et al*., 2021). Several cases due to mercury contamination have also been reported in several countries such as the United States, Pakistan, Indonesia, Ghana, Suriname, and Slovakia (Angelovičová and Fazekašová, 2014; Bortey-Sam *et al*., 2015; Brent and Berberich, 2014; Peplow and Augustine, 2014; Riaz *et al*., 2018; Zuas *et al*., 2021). Besides being harmful to human health, mercury has an impact on the loss of processes and equipment in the industry. For example, mercury affects the cracking and corrosion of cryogenic vessels. Mercury-contaminated liquids and sorbents result in delayed processing and disposal. In addition, mercury exposure is dangerous for other industrial equipment such as separators, heat exchangers, and agricultural tanks (Palathoti *et al*., 2022).

Currently, various reports have been published on mercury and its effects on human health and environmental safety. However, systematic reviews to identify research trends, provide information, and assess the quality of developments on the topic of mercury, especially in the gold mining sector, have not provided adequate information. Therefore, we conducted a bibliometric analysis for this research topic to analyze the literature related to the use of mercury in gold mining.

Bibliometric analysis is a systematic review method that identifies research trends and current issues based on the history of a publication to gain an overview of a research field and to produce results with more in-depth content analysis. Recently, many reports on bibliometric analysis have been published to understand research trends on a specific topic (Al Husaeni and Nandiyanto, 2022; Al Husaeni and Nandiyanto, 2022; Al Husaeni *et al*., 2023; Al Husaeni and Nandiyanto, 2023; Bilad, 2022; Fauziah, 2022; Hamidah *et al*., 2020; Hammouti, 2010; Hirawan *et al*., 2022; Kurniati *et al*., 2022; Luckyardi *et al*., 2022; Morante-Carballo *et al*., 2022; Mudzakir *et al*., 2022; Mulyawati and Ramadhan, 2021; Nandiyanto and Al Husaeni, 2022; Nandiyanto, Al Husaeni, *et al*., 2021; Nandiyanto and Al Husaeni, 2021; Nandiyanto *et al*., 2023; Nandiyanto, Biddinika, *et al*., 2020; Nandiyanto *et al*., 2022; Nordin, 2022a, 2022b; A. S. Nugraha, 2022; Palathoti *et al*., 2022; Ragadhita and Nandiyanto, 2022a; Ramadhan *et al*., 2023; Riandi *et al*., 2022; Saputra *et al*., 2022; Setiyo *et al*., 2021; A. P. Shidiq, 2021; A. S. Shidiq *et al*., 2021; Soegoto *et al*., 2022; Sudarjat, 2023; Wiendartun *et al*., 2022; Wirzal and Putra, 2022; Wong *et al*., 2021; Wong *et al*., 2020; Zuas *et al*., 2021; Zupic and Čater, 2015).

Bibliometric analysis is employed to get quantitative analysis, gaining the distribution pattern of articles related to a topic, field, author, institution, or country by developing objective criteria used to select, review, and track published research. The specific purpose of this research is to collect data on the development of research article documents from 2018 to 2022. Articles with the most citations,

productive publishers publishing related articles, visualization analysis, network analysis, and cluster analysis. This study also includes a review of the prospects related to the study's topic.

2. Previous Studies on Artisanal and Small-Scale Gold Mining

Mining is a series of activities in the context of searching, extracting, processing, utilizing, and selling minerals (i.e., minerals, coal, geothermal, oil and gas). Mercury-based ASGM is a mining activity that is still widely practiced in several developing countries. Only a small proportion of industries have switched to processes for not using mercury, such as the use of cyanide, borax, or physical separation with a sieve. This possesses the environment to be exposed to mercury. Specifically, it is from the residue from the process which is wasted directly without processing into the environment (Seccatore *et al*., 2014; Veiga *et al*., 2006).

In the ASGM process, mercury is used to bind gold from ore as a stable amalgam. The amalgam is then heated until the mercury evaporates, and the mercury isolates the gold. Mercury is used in the mining process because it is easy to use, available, and inexpensive (Moody *et al*., 2020). In practice, mining gold using mercury takes only half a day. In the morning, rocks containing gold are excavated from the ground. And, in the afternoon, gold can be obtained using mercury. When mining is carried out, it is estimated that around 410 to 1400 tons of mercury are released into the environment annually, accounting for about 37% of global mercury emissions (Esdaile and Chalker, 2018; Yang *et al*., 2020; Yoshimura *et al*., 2021).

Figure 1 shows the main method of gold (Au) extraction using the ASGM technique. Detailed information on the step-by-step ASGM process is explained in the following (Yoshimura *et al*., 2021):

(i) Rock Grinding Process. Natural rock obtained from mining pits or called ore is refined utilizing grounding or crushing processes to get ore smaller.

(ii) Amalgamation Process. The ground rock is then amalgamated using mercury. The mercury required to extract gold is about 10-25 g for every 1 g of gold produced. Meanwhile, the concentrate amalgamation process only requires 1-3 g of mercury. This amalgamation process aims to bind gold.

(iii) Evaporation Process. To separate the metal-containing gold from the mercury, an evaporation process is carried out through combustion. Burning is usually done in an open process. Thus, the mercury that is still bound in the amalgam will evaporate into the air. The results of the evaporation process are gold sponges (non-pure gold products), containing some metal impurities such as silver or copper.

(iv) Smelting and Refining Process. To get gold metal, gold bullion deposits (High Au Bullion) are then smelted with the addition of borax ($Na_2B_4O_7.10H_2O$) to bind any remaining impurities or other metal impurities such as silver or copper.

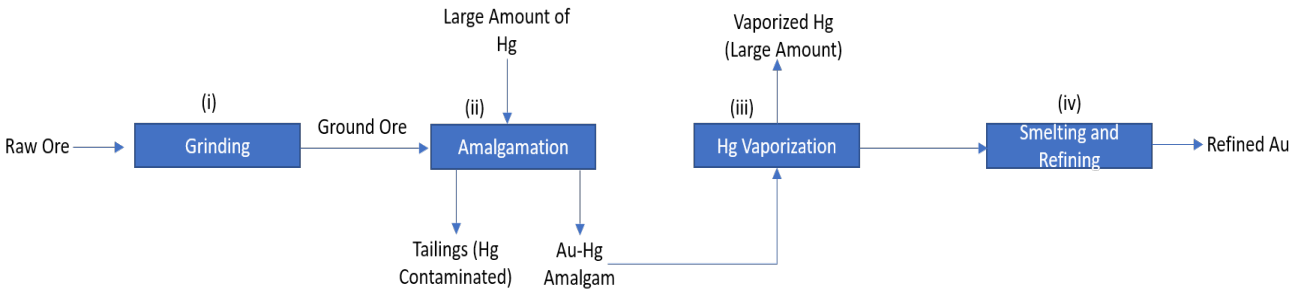

Figure 1. Simple flowchart illustration of the ASGM process (Adopted from literature (Yoshimura *et al.*, 2021)

Previous explanations have exemplified the use of mercury in anthropogenic activities. Mercury is a type of heavy metal that has very toxic properties for humans (Veiga and Fadina, 2020). It is the highest toxic properties compared to other metals such as Arsenic (As), Lead (Pb), Chromium (Cr), Silver (Ag), Nickel (Ni), Zinc (Zn), Tin (Sn), and Cadmium (Cd) (Palani *et al*., 2022; Sandeep *et al.,* 2019). In most ASGM processing steps, mercury is used in the amalgamation process, and the amount of environmental emissions depends on the method used. The use of mercury in the amalgamation process can contaminate soil, water, and air. This is due to the evaporation of mercury in the heating (coaling) process in retorting step. It can contaminate the air. The remaining mercury in tailings is discharged directly into the land or water environment (Mantey *et al*., 2020). Exposure to mercury elements in mining areas causes neurological symptoms because high concentrations of mercury enter the blood; thus, it undergoes transportation and disposition in the body. In the environment, mercury consists of three forms, namely elemental, organic, and inorganic forms. All forms of mercury cause effects on destroying tissues and organs. Its damage depends on the form, level of exposure, duration of exposure, and route of exposure. The kidney is the main target organ where mercury is taken up. When it accumulates, it brings and causes toxic effects. Inorganic mercury is more toxic to the kidneys than organic mercury. However, organic mercury is more capable of causing systemic effects, including the hematopoietic system and nervous tissue (Afrifa *et al*., 2029). Table 1 summarizes the health implications due to mercury exposure from ASGM activities.

Table 1. Health implications due to mercury exposure

Symptom	Effects	Year	Country	References
Neurological effect	Mercury levels in urine and hair have risen.	2016	Indonesia	(Bose-O'Reilly *et al*., 2016)
		2014	Surinam	(Peplow *et al*., 2014)
		2000	Brazil	(Dolbec *et al*., 2016)
Renal abnormalities	• eGFR decrease, urine protein increase • Increase in proteinuria	2017 2015 2005	Ghana Indonesia Nigeria	(Afrifa *et al*., 2017) (Ekawanti and Krisnayanti *et al*., 2015)
Thyroid risks	Total triiodothyronine, free triiodothyronine, and free thyroxine levels were reduced.	2018	Sudan	(Tayrab, 2017)
Haemato-pathological risk	Reduced hemoglobin and hematocrit Levels	2015	Indonesia	(Ekawanti and Krisnayanti *et al*., 2015)
Oxidative stress in DNA	Changes in membrane permeability and macromolecular structure	2008	India	(Flora and Mittal, 2008)
Genotoxic effects	Micronuclei in mouth epithelial cells, nucleoplasmic bridges, gemmation, and binucleation	2013	Peru	(Afrifa *et al*., 2017)

Heavy metals including mercury can enter the aquatic environment through precipitation, dilution, and dispersion mechanisms. Then, it can be absorbed by organisms living in these waters. If the solubility of the components formed between metals and acids present in the water (such as carbonates, hydroxyl, and chlorides) is smaller than the concentration of heavy metals, the process of precipitation of heavy metals will occur. One of the pollutants resulting from human activities that can contaminate rivers is toxic chemicals from heavy metals, such as mercury and sediment. In short, the mechanism for the entry of mercury into the human body is from the evaporation of mercury which is inhaled and absorbed into the blood. Thus, it is transported in the body. Then, Hg^0 gas is oxidized into intracellular. Hg^{2+} ions accumulate in the kidney and are retained in the brain causing damage to that part.

3. Methodology

An illustration of the methodological design stages related to bibliometric analysis in mercury research is shown in **Figure 2**. Detailed information for the experiment is in the following:

(i) Harvesting Data. Analysis of research trends was carried out by collecting related articles that have been published using the Google Scholar database using the Publish or Perish software. We collected data on 20-25 October 2022. The data search was carried out over 5 years (2018-2022). The keywords used in the search for related articles were "mercury", "gold mining", "particle technology", and "adsorption". Document search was filtered by document types in the form of journals, conference proceedings, and books, but we excluded patents. The results of harvesting data found more than 999 research articles related to mercury for gold mining. The articles were then put into Microsoft Excel software and saved in a comma-separated value format (*.csv). In this study, Google Scholar was selected as the database in the bibliometric analysis because it is one of the largest free scientific bibliography databases. Google Scholar also relies on aggregating a large number of classified databases, the contents of which are not accessible via the public internet. Thus, Google Scholar can be compared to two other large databases that are both expensive sources of scientific bibliography: Web of Knowledge (edited by ISI/Thomson) and Scopus (developed by Elsevier).

(ii) Screening Data. The data that has been obtained and collected from the data harvesting process cannot be directly analyzed. Therefore, data screening needs to be done. At this stage, data screening was carried out by observing the title of the article and the year of publication of the article. Articles with irrelevant titles and an incomplete year of publication were discarded. The cleaned data was then constructed into a Microsoft Excel file for further analysis using bibliometric software. After data screening was carried out, 988 articles met the requirements for further analysis.

(iii) Data Analysis and Visualization. Selected documents that have been cleaned and stored in the Microsoft Excel program were converted into .ris format. We then opened and visualized the data. Trend analysis was performed using bibliometric analysis software (VOSViewer). In this stage, we filtered the terms included in the VOSviewer network mapping visualization. The article data was mapped using the source database. We used three forms of data mapping: network, density, and overlay visualizations. Detailed information for data analysis and visualization using VOSviewer and Publish or Perish software is explained elsewhere (Al Husaeni and Nandiyanto, 2022).

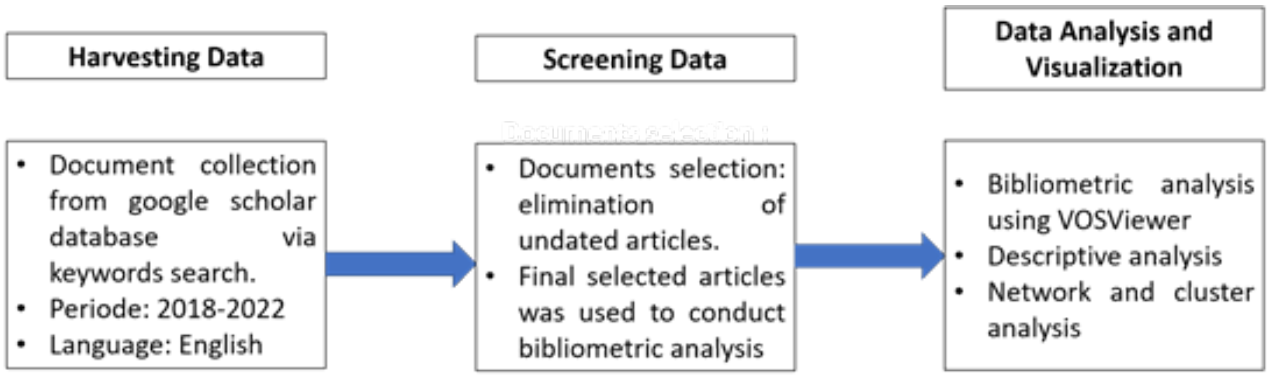

Figure 2. Methodology design of bibliometric analysis on mercury research

4. Results and Discussion

4.1 Publication trend on the mercury research

Various studies on research regarding gold mining using mercury have determined the level of publication. Data after the screening process through Publish or Perish software with the keywords of "mercury", "gold mining", "particle technology", and "adsorption" resulted in 988 articles from various institutions in the world. **Figure 3** shows the published document trend in mercury research from 2018 to 2022. The number of publications increased from 195 to 239 between 2018 and 2022, with a progressively decreasing trend from 2021 to 2022. The highest trend rate for publications related to gold articles using mercury was in 2020. The lowest trend rate for publications of gold mining articles using mercury is in 2022 which is only 12% of articles from the total publication over the previous 5 years. The increased publication of mercury-related articles from 2018 to 2020 was due to increases in the awareness of health, safety, and the environmental impact of mercury during that period. Furthermore, global exploitation of the mercury-based mining sector increased during the same period (Palathoti *et al*., 2022).

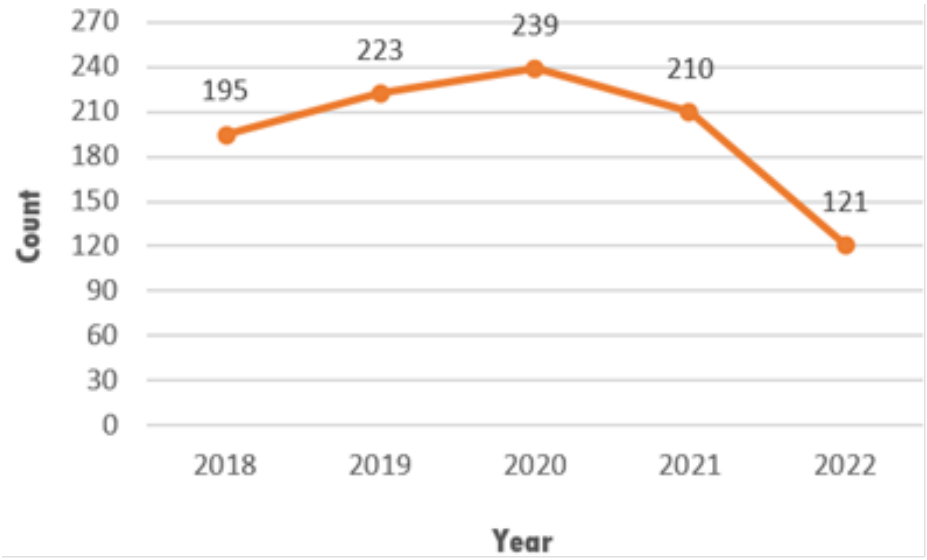

Figure 3. Annual Publication trends for Mercury in Gold Mining Research (2018-2022)

4.2 The most cited article

Analysis of authors and publications with the most top citations is one of the important factors for analyzing research and research developments in various fields (Wong *et al*., 2021; Wong *et al*., 2020). Articles related to mercury with 25 top citations based on the Google Scholar database in the period 2018-2022 are presented in Table 2. The top 25 citations on mercury research topics came from 52% of review publications and 48% of publications in journal articles or articles. When viewed from the number of citations, publication reviews accounted for 5504 citations (60.11%). Meanwhile, research articles accounted for 3652 citations (39.88%). The publication that was most cited was the review publication entitled "Sustainable Technologies for Water Purification from Heavy Metals: Review and Analysis" by Bolisetty *et al*. published in the journal Chemical Society Reviews. The second and third ranks of top citations are articles entitled "Environmental Contamination by Heavy Metal" with the type of research article document and "Dyes Adsorption using Clay and Modified Clay: A Review" with a review publication document type.

Table 2. 25 Top-cited articles on mercury research

First Author	Title	Journal	Type	Citation
Bolisetty, S	Sustainable technologies for water purification from heavy metals: review and analysis	Chemical Society Reviews	Review	714
Masindi, V.	Environmental contamination by heavy metals	Heavy Metals	Article Journal	637
Kausar, A.	Dyes adsorption using clay and modified clay: a review	Journal of Molecular Liquids	Review	622
Singh, N. B.	Water purification by using adsorbents: a review	Environmental Technology and Innovation	Review	577
Yang, X.	Surface functional groups of carbon-based adsorbents and their roles in the removal of heavy metals from aqueous solutions: a critical review	Chemical Engineering Journal	Review	562
Xu, J.	A review of functionalized carbon nanotubes and graphene for heavy metal adsorption from water: Preparation, application, and mechanism	Chemosphere	Review	549
Rahman, Z.	The relative impact of toxic heavy metals (THMs)(arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview	Environmental Monitoring and Assessment	Review	423
Barboza, L.G.A.	Microplastics cause neurotoxicity, oxidative damage and energy-related changes and interact with the bioaccumulation of mercury in the European seabass …	Aquatic Toxicology	Article Journal	412
Lu, F.	Nanomaterials for removal of toxic elements from water	Coordination Chemistry Reviews	Article Journal	338
Guerra, F. D.	Nanotechnology for environmental remediation: materials and applications	Molecules	Article Journal	317
Awual, M. R.	Efficient detection and adsorption of cadmium (II) ions using innovative nano-composite materials	Chemical Engineering	Article Journal	314
Sherlala, A. I. A.	A review of the applications of organo-functionalized magnetic graphene oxide nanocomposites for heavy metal adsorption	Chemosphere	Review	310
Araújo, C. S.	Elucidation of mechanism involved in adsorption of Pb (II) onto lobeira fruit (Solanum lycocarpum) using Langmuir, Freundlich and Temkin isotherms	Microchemical Journal	Article Journal	304
Efome, J. E.	Insight studies on metal-organic framework nanofibrous membrane adsorption and activation for heavy metal ions removal from aqueous solution	ACS Applied Material and Interfaces	Article Journal	244
Fiyadh, S. S.	Review on heavy metal adsorption processes by carbon nanotubes	Journal of Cleaner Production	Review	239

Table 2 (continue). 25 Top-cited articles on mercury research

First Author	Title	Journal	Type	Citation
Fiyadh, S. S.	Review on heavy metal adsorption processes by carbon nanotubes	Journal of Cleaner Production	Review	239
Vakili, M.	Regeneration of chitosan-based adsorbents used in heavy metal adsorption: A review	Separation and Purification Technology	Review	237
Sajid, M.	Removal of heavy metals and organic pollutants from water using dendritic polymers-based adsorbents: a critical review	Separation and Purification Technology	Review	236
Abbas, K.	A ligand anchored conjugate adsorbent for effective mercury (II) detection and removal from aqueous media	Chemical Engineering Journal	Article Journal	233
Saleem, J.	Production and applications of activated carbons as adsorbents from olive stones	Biomass Conversion and Biorefinery	Article Journal	231
Vikrant, K.	Nanomaterials for the adsorptive treatment of Hg (II) ions from water	Chemical Engineering Journal	Article Journal	224
Zhao, S.	A review on mercury in coal combustion process: Content and occurrence forms in coal, transformation, sampling methods, emission, and control technologies	Progress in Energy and Combustion Science	Review	214
Zhu, L.,	Shapeable fibrous aerogels of metal–organic-frameworks templated with nanocellulose for rapid and large-capacity adsorption	ACS Nano	Article Journal	205
O'Connor, D.	Mercury speciation, transformation, and transportation in soils, atmospheric flux, and implications for risk management: A critical review	Enviroment International	Review	196
Supanchaiyamat, N.	Lignin materials for adsorption: Current trend, perspectives and opportunities	Bioresource Technology	Article Journal	193

4.3 Co-authorship analysis

Collaboration in research is highly expected because research is not always done independently individual. For this reason, collaboration is needed both in terms of ideas, funds, facilities, infrastructure, opportunities to share knowledge, and certain techniques in science (Tabatabaei-Malazy *et al*., 2016). A poor co-authoring network suggests a lack of communication, collaboration, and productivity. Furthermore, documents produced through scientific collaboration can have a greater impact and are more likely to be cited (Tahamtan *et al*., 2016). **Figure 4** shows the author's visualization. The results of the author's collaboration analysis showed nodes consisting of 6 main collaborative clusters. In this study, out of 999 authors, 25 authors had a strong relationship. Each author in each link group is different. The author with the most links is Wang, Y.

4.4 Co-Occurrence keyword network

VOSviewer can display bibliometric mappings in three different visualizations; network visualization (**Figure 5**), overlay visualization (**Figure 6**), and density visualization (**Figure 7**). Co-occurrence analysis is an analysis of the results of the formation of connections from the author's words based on

keywords (Al Husaeni and Nandiyanto, 2022; Zupic and Čater, 2015). The relationship of several keywords in international publications related to the topic of discussion is connected by a network or line that comes from one term to another (Al Husaeni and Nandiyanto, 2022).

Figure 4. Author Collaboration Visualization

Figure 5 shows the relationship between terms. The co-occurrence visualization map has succeeded in grouping 150 keywords into clusters of different colors which are grouped into 5 item clusters representing the main research area containing 109 items, 3176 links, and a total link strength of 13615. Some common irrelevant and frequently occurring terms with no special meaning were marked in the program with low relevance scores and were thus excluded from the analysis. Figure 5 depicts a term map based on the shared frequency of occurrence, with five groups of related concepts depicted in various colors.

Each node in the network represents an entity (for example, articles, authors, countries, institutions, keywords, journals) (Morante-Carballo *et al*., 2022; Donthu *et al*., 2021), and in the case shown in Figure 3 there are several descriptions, including:

(i) Color node measures indicate keyword occurrence (i.e., how many times the keyword occurs),
(ii) relationships between nodes represent co-occurrence between keywords (that is, keywords that occur together or occur together),
(iii) link number indicates co-occurrence between keywords (i.e., number of times keywords co-occur or occur together),
(iv) the bigger the node, the bigger the keywords appear. The bigger node is the “adsorption” cluster (blue node) and followed by the “mercury” cluster (green node).

(v) the thicker the links between nodes, the greater the co-occurrence between keywords.
(vi) Each color represents a thematic cluster, where the nodes and links within the cluster can be used to explain the scope of the topic (node) of the theme (cluster) and the relationship (link) between the topics (nodes) that materialize under that theme (cluster).

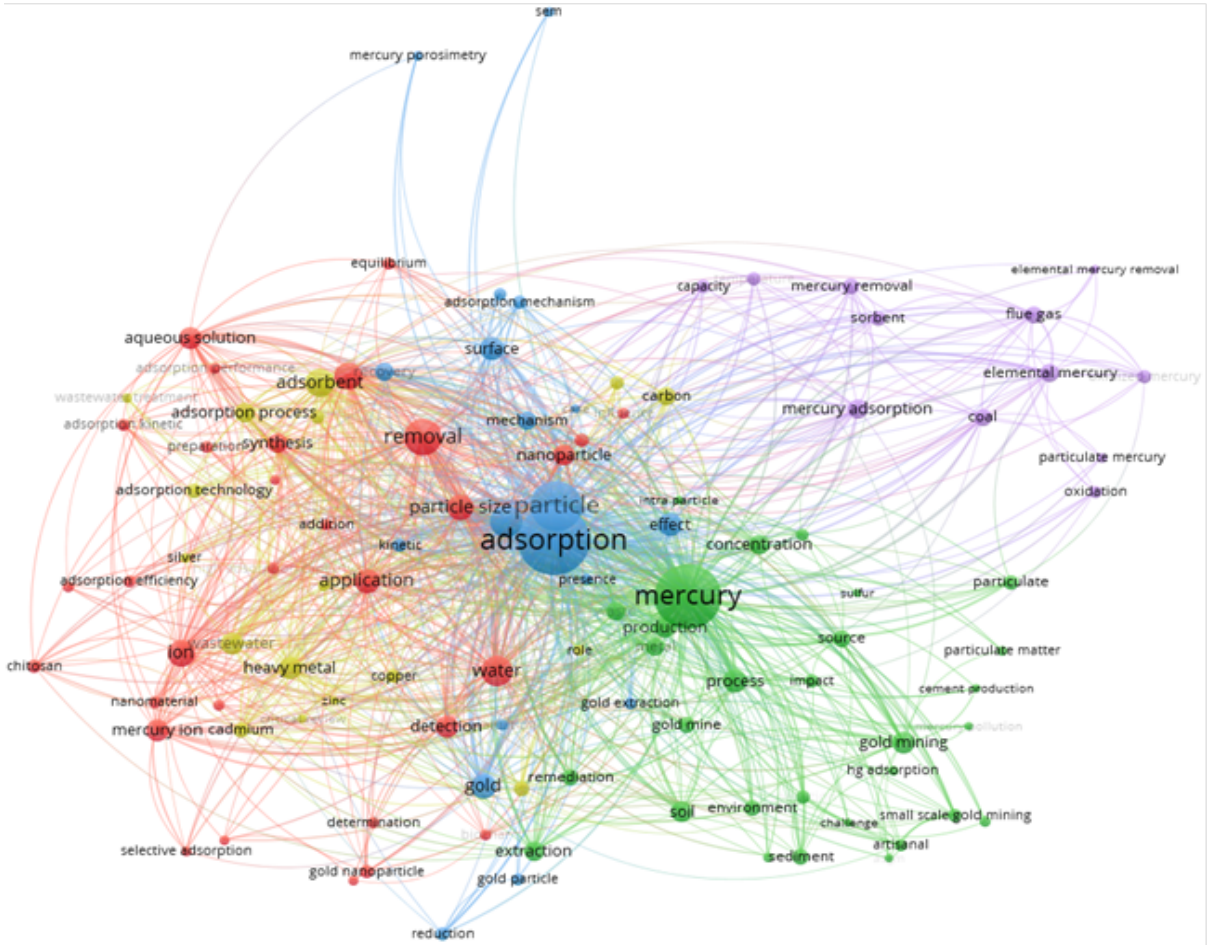

Figure 5. Network visualization of mercury-related research

Research related to gold mining using mercury based on mapping visualization is divided into 5 clusters, including:

(i) Cluster 1. Cluster 1 has a red color which corresponds to 31 items such as adsorption capacity, adsorption efficiency, adsorption isotherm, adsorption kinetic, addition, adsorption performance, adsorption property, adsorption rate, application, aqueous solution, biochar, chitosan, detection, determination, equilibrium, gold nanoparticle, heavy metal ion, high adsorption capacity, influence, ion, maximum adsorption capacity, mercury ion, ppm, nanomaterial, nanoparticle, particle size, preparation, removal, selective adsorption, synthesis, and water. Based on the term relationship in cluster 1, cluster 1 discusses the mercury removal treatment process in the mining sector using adsorbents or known as adsorption technology. The process of removing these pollutants needs to be carried out, especially in environments exposed to pollutants due to the existence of the mining sector because mining activities have an impact on increasing levels of environmental pollution, especially soil and water by mercury (Bempah and Ewusi, 2016; Chen *et al*., 2019; Lrhoul *et al*., 2021).

(ii) Cluster 2. Cluster 2 is marked with a green color corresponding to 30 items such as artisanal, artisanal gold mining, ASGM, cement production, challenge, concentration, environment, extraction, gold mine, gold mining, Hg adsorption, impact, intra particle, mercury, mercury

pollution, mercury species, metal, particulate, particulate matter, process, production, progress, remediation, sediment, small scale gold mining, soil, source, speciation, sulfur, and wastes. Mercury is a heavy, liquid metal frequently used in artisanal gold mining (Morante-Carballo *et al*., 2022). Mercury is often used by miners in the ASGM sector to bind gold because the process is fast and easy. In the ASGM business activities, ore processing is carried out by an amalgamation process where mercury is used as a medium to bind gold. Amalgamation is a method that is often used by traditional small-scale gold miners to separate gold from chemical binders (Esdaile and Chalker, 2018; Yoshimura *et al*., 2021).

(iii) Cluster 3. Cluster 3 has a blue color associated with 19 items such as adsorption, adsorption mechanism, case, effect, evaluation, gold, gold extraction, gold particle, isotherm, kinetic, mechanism, mercury porosimetry, particle, recovery, reduction, SEM, study, and surface. The adsorption technique is usually a simple way of treating water. In the mining process, the mercury produced is deposited on the surface which results in the entry of mercury pollution into the soil and the groundwater environment through the pores carried by rainwater that enters the soil (Qu *et al*., 2019). Thus, the soil is one of the most connecting media between the atmosphere and water which is very important for the global mercury cycle (Reis *et al*., 2016). Based on this case, one of the techniques used for water treatment is the adsorption technique. Adsorption is the process of clumping dissolved substances in solution by the surface of the adsorbent which makes the material enter and collect in an absorbent substance. Detailed information on adsorption is explained in our previous studies (Fiandini *et al*., 2020; Maryanti *et al*., 2020; Nandiyanto, 2020; Nandiyanto, Girsang, *et al*., 2020; Nandiyanto, Hofifah, *et al*., 2021; Nandiyanto, Ragadhita, *et al*., 2020; Ragadhita and Nandiyanto, 2021, 2022b). In adsorption, there are so-called adsorbents and adsorbates. The adsorbent is an absorbent substance, while the adsorbate is a substance that is absorbed. Adsorbents usually use materials that have pores. Thus, the adsorption process occurs in the pores or at certain locations within the particle. In general, the pores contained in the adsorbent are usually very small, thus the inner surface area becomes larger than the outer surface. Separation occurs because of differences in molecular weight or because of differences in polarity which causes some molecules to adhere to the surface more tightly than other molecules.

(iv) Cluster 4. Cluster 4 is marked with a yellow node containing 17 items such as activated carbon, adsorbent, adsorption process, adsorption technology, arsenic, cadmium, carbon, chromium, copper, critical review, heavy metal, intra particle diffusion, role, silver, wastewater, wastewater treatment, and zinc. The term relationship in cluster 4 implies that cluster 4 discusses the use of adsorbents to remove heavy metal content such as arsenic, cadmium, chromium, copper, silver, and others that accumulate in the water. In cluster 4, it is also stated that one of the adsorbent materials commonly used for water treatment is carbon particles (Maryanti *et al*., 2020). Carbon particles are often used for water treatment with the adsorption method because they can be fabricated from everyday products and even from waste such as domestic waste and agricultural waste (Fiandini *et al*., 2020; Maryanti *et al*., 2020). In addition, carbon has the characteristics of a porous structure that provides a large surface area so that it is easy to absorb pollutants.

(v) Cluster 5. Cluster 5 has a purple color containing 12 items such as capacity, coal, elemental mercury, elemental mercury removal, flue gas, mercury adsorption, mercury removal, oxidation, oxidized mercury, particulate mercury, sorbent, and temperature. This cluster is related to the study of mercury adsorption from the mining sector. ASGM is the most developed mining activity based on the obtained literature review and analysis. The significant environmental and health impacts caused by ASGM are evident in this research area. Mercury pollution is often investigated in the

soil, water, plants, or trees due to direct or indirect exposure. Therefore, mercury is certain to have a negative impact on the environment, health, and safety (Morante-Carballo *et al*., 2022). When faced with this problem, it is standard practice to conduct innovative research to eliminate, replace, or reduce environmental pollution in mineral processing (Morante-Carballo *et al*., 2022; Veiga *et al*., 2006). Given the adverse effects of mercury on the environment and health, it is important to conduct research that highlights and focuses on reducing mercury-induced pollution to ensure human and environmental health. Some examples of research that focuses on the removal and treatment of mercury waste in the ASGM are the use of adsorption methods with zeolite adsorbents (Prasetya *et al*., 2020), the use of acid extraction methods (Nugraha *et al*., 2021), the use of phytoremediation methods (Ebel *et al*., 2007), and ultrasonic irradiation (Willy Cahya Nugraha *et al*., 2022).

Figure 6 shows the trend of research on related topics by year in scientific publications from 2018-2022. The overlay visualization image shows that dense colors show the results of many studies that have been done and bright colors indicate the latest research that has been done (Al Husaeni *et al*., 2023).

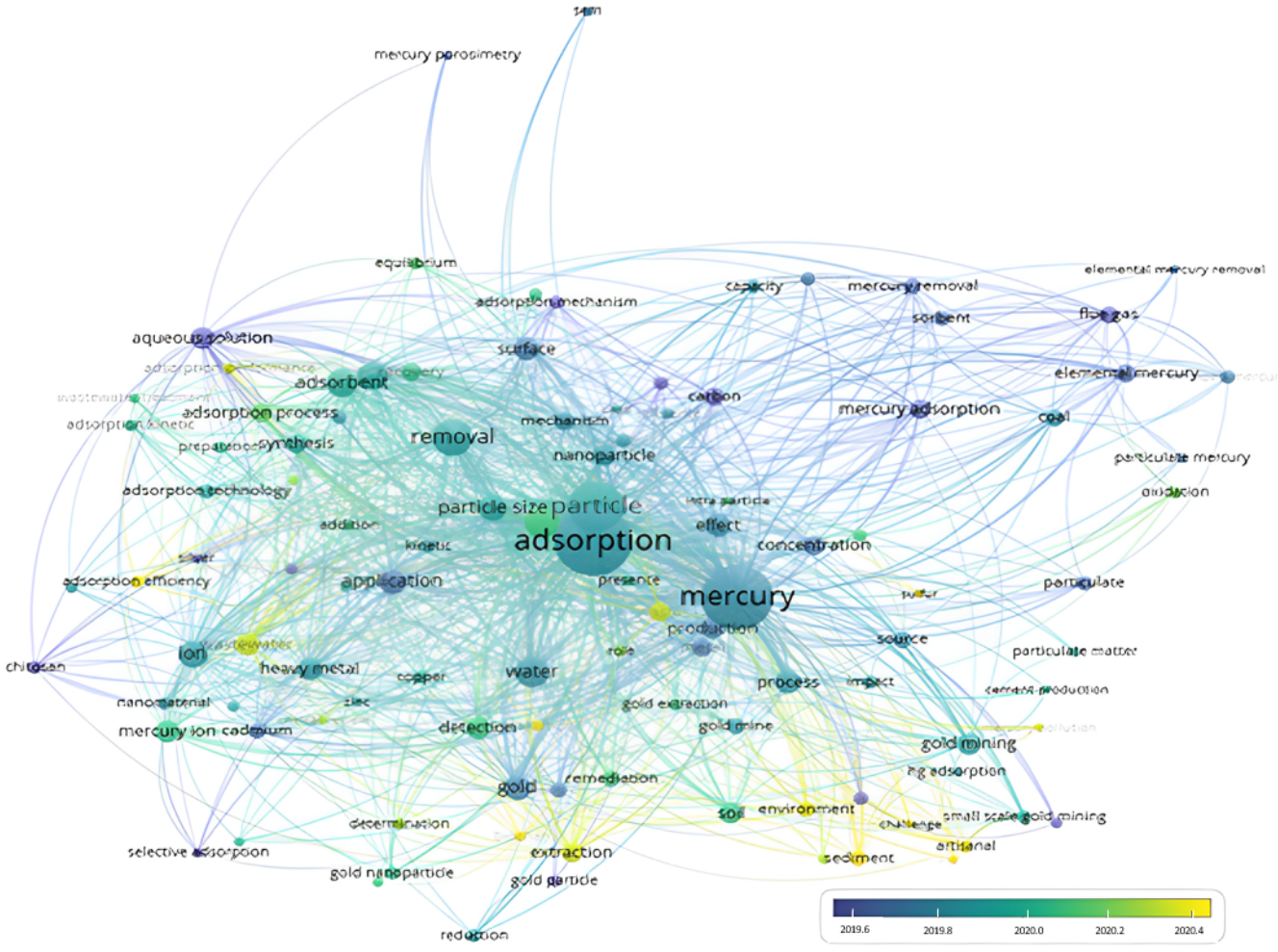

Figure 6. Overlay visualization on mercury research

Based on **Figure 6**, when viewed from the most recent research in 2022 (see yellow nodes in **Figure 6**), research and publications related to the topic of mercury in the mining sector began to lead to research on the impact of mercury on the environment and health and lead to research to eliminate,

replace, or reduce environmental pollution in mineral processing with mercury, especially for the treatment of mercury-contaminated water. This is based on the visualization results which show yellow nodules representing the latest years of publication of scientific publications containing keywords including “wastewater”, adsorption efficiency”, “extraction”, “environment”, “mercury pollution”, “sediment”, “mercury”, “artisanal”, “sulfur”, and “adsorption performance”.

The density visualization results are shown in **Figure 7**. The density visualization shows the depth of the item density visualization. Each item point in the density visualization has a color that indicates the density of the item at that point. By default, colors range from blue to green to yellow. The greater the number of items in the dot neighborhood and the higher the weight of the surrounding items, the closer the dot color is too yellow. This section is very useful for getting an overview of the general structure of a bibliometric map by noting which parts of the items are considered important for analysis. Through this analysis, we can interpret the most used keywords in a publication. The keywords of “mercury” and “adsorption” have higher link strength values than other keywords. The more concentrated the color resulted the more researchers used the topic keywords of “adsorption” and “mercury”.

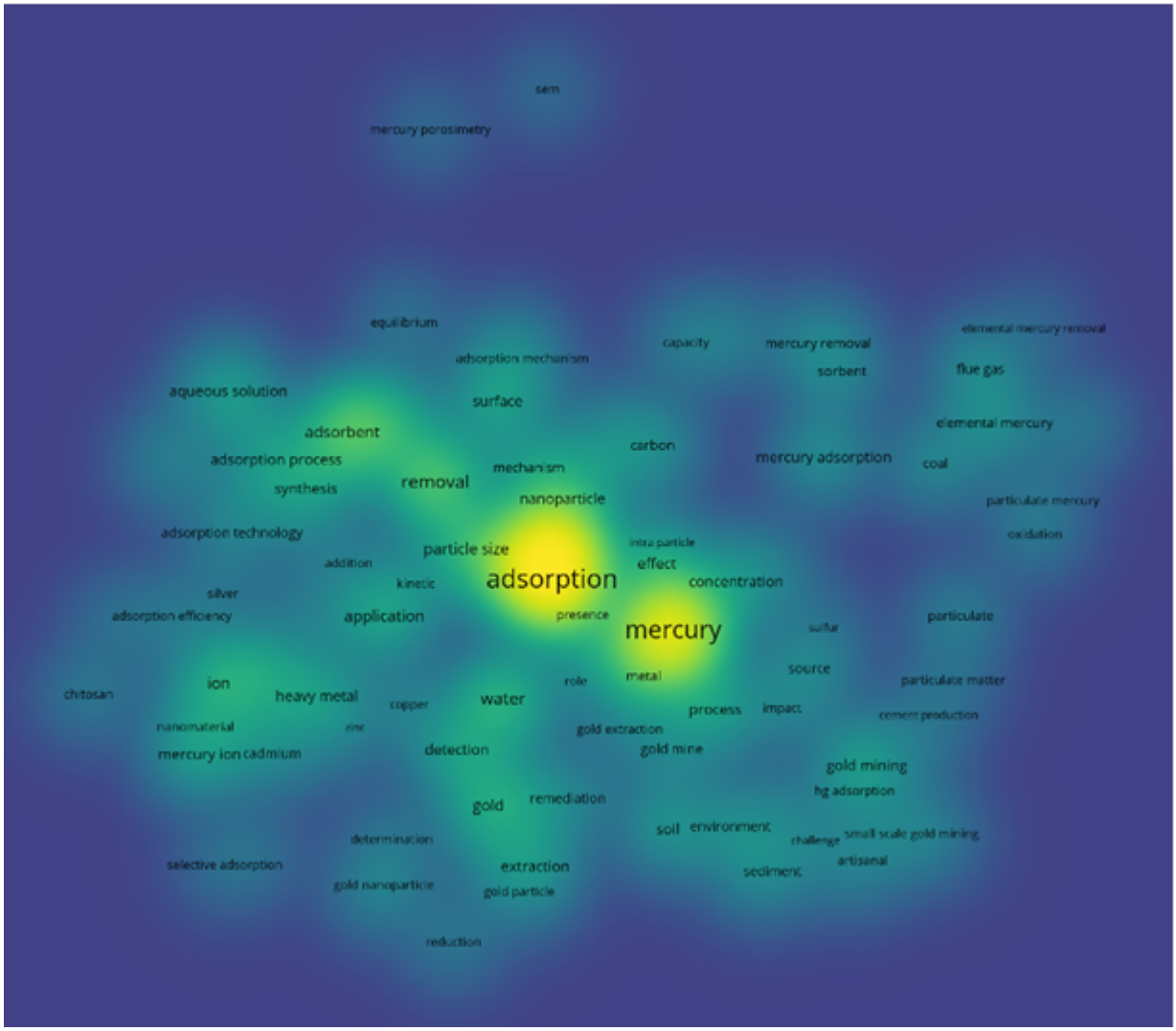

Figure 7. Density visualization on mercury research

Conclusion

Based on the analysis of research on mercury in gold mining from 2018 to 2022, the highest number of publications occurred in 2020 with 239 publications. However, the number continued to decline the following year, 2021–2222. The results of the mapping of research development showed that the use of mercury-related applications in the ASGM is still the main issue. This informs further analysis and innovations for finding alternative materials of mercury is important to be done.

Acknowledgment: This study acknowledged RISTEK DIKTI for Grant-in-aid Penelitian Terapan Unggulan Perguruan Tinggi (PTUPT) and Universitas Pendidikan Indonesia for Bangdos.

References

Afrifa J., Opoku, Y. K., Gyamerah, E. O., Ashiagbor, G., Sorkpor, R. D., (2019). The clinical importance of the mercury problem in artisanal small-scale gold mining. *Frontiers in Public Health*, *7*, 131. doi: https://doi.org/10.3389/fpubh.2019.00131

Al Husaeni D. F., Nandiyanto A. B. D., (2022) Bibliometric using Vosviewer with Publish or Perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post Covid-19 pandemic. *ASEAN Journal of Science and Engineering, 2*(1), 19-46

Al Husaeni D. F., Nandiyanto A. B. D., Maryanti R., (2023) Bibliometric analysis of educational research in 2017 to 2021 using VOSviewer: Google scholar indexed research. *Indonesian Journal of Teaching in Science, 3*(1), 1-8

Al Husaeni D. N., Nandiyanto A. B. D., (2022) Bibliometric computational mapping analysis of publications on mechanical engineering education using vosviewer. *Journal of Engineering Science and Technology, 17*(2), 1135-1149

Al Husaeni D. N., Nandiyanto A. B. D., (2023) A bibliometric analysis of vocational school keywords using vosviewer. *ASEAN Journal of Science and Engineering Education, 3*(1), 1-10

Angelovičová L., Fazekašová D., (2014) Contamination of the soil and water environment by heavy metals in the former mining area of Rudňany (Slovakia). *Soil and Water Research, 9*(1), 18-24

Bempah C. K., Ewusi A., (2016) Heavy metals contamination and human health risk assessment around Obuasi gold mine in Ghana. *Environmental Monitoring and Assessment, 188*(5), 1-13

Bilad M. R., (2022) Bibliometric analysis for understanding the correlation between chemistry and special needs education using vosviewer indexed by google. *ASEAN Journal of Community and Special Needs Education, 1*(2), 61-68

Bortey-Sam N., Nakayama S. M., Ikenaka Y., Akoto O., Baidoo E., Yohannes Y. B., Mizukawa H., Ishizuka M., (2015) Human health risks from metals and metalloid via consumption of food animals near gold mines in Tarkwa, Ghana: Estimation of the daily intakes and target hazard quotients (THQs). *Ecotoxicology and Environmental Safety, 111*, 160-167. doi: https://doi.org/10.1016/j.ecoenv.2014.09.008

Bose-O'Reilly, S., Schierl, R., Nowak, D., Siebert, U., William, J. F., Owi, F. T., Ir, Y. I., (2016). A preliminary study on health effects in villagers exposed to mercury in a small-scale artisanal gold mining area in Indonesia. *Environmental research*, *149*, 274-281. doi: https://doi.org/10.1016/j.envres.2016.04.007

Brent R. N., Berberich D. A., (2014) Use of artificial stream mesocosms to investigate mercury uptake in the South River, Virginia, USA. *Archives of Environmental Contamination and Toxicology, 66*(2), 201-212. doi: https://doi.org/10.1007/s00244-013-9964-7

Carravieri A., Cherel Y., Brault-Favrou M., Churlaud C., Peluhet L., Labadie P., Budzinski H., Chastel O., Bustamante P., (2017) From Antarctica to the subtropics: Contrasted geographical concentrations of selenium, mercury, and persistent organic pollutants in skua chicks (Catharacta spp.). *Environmental*

Pollution, 228, 464-473. doi: https://doi.org/10.1016/j.envpol.2017.05.053

Chen M., Li F., Hu L., Yang T., Yang Q., Tao M., Deng Y., (2019) Heavy metal pollution in topsoil and vegetables in the typical mining area near Gannan, Jiangxi Province, China. *Environmental Engineering Science, 36*(10), 1307-1314. doi: https://doi.org/10.1089/ees.2019.0013

Diaz F. A., Katz L. E., Lawler D. F., (2020) Mercury pollution in Colombia: challenges to reduce the use of mercury in artisanal and small-scale gold mining in the light of the Minamata Convention. *Water International, 45*(7-8), 730-745. doi: https://doi.org/10.1080/02508060.2020.1845936

Dolbec, J., Mergler, D., Sousa Passos, C. J., Sousa de Morais, S., Lebel, J., (2000). Methylmercury exposure affects motor performance of a riverine population of the Tapajos river, Brazilian Amazon. *International Archives of Occupational and Environmental Health*, *73*(3), 195-203. doi: https://doi.org/10.1007/s004200050027

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., Lim, W. M., (2021). How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research, *133*, 285-296. doi: https://doi.org/10.1016/j.jbusres.2021.04.070

Ebel M., Evangelou M. W., Schaeffer A., (2007) Cyanide phytoremediation by water hyacinths (Eichhornia crassipes). *Chemosphere, 66*(5), 816-823

Ekawanti, A., Krisnayanti, B. D., (2015). Effect of mercury exposure on renal function and hematological parameters among artisanal and small-scale gold miners at Sekotong, West Lombok, Indonesia. Journal of *Health and Pollution*, *5*(9), 25-32. doi: https://doi.org/10.5696/2156-9614-5-9.25

Esdaile L. J., Chalker J. M., (2018) The mercury problem in artisanal and small-scale gold mining. *Chemistry–A European Journal, 24*(27), 6905-6916. doi: https://doi.org/10.1002/chem.201704840

Fauziah A., (2022) A Bibliometric analysis of nanocrystalline cellulose production research as drug delivery system using VOSviewer. *Indonesian Journal of Multidiciplinary Research, 2*(2), 333-338. doi: https://doi.org/10.17509/ijomr.v2i2.43341

Fiandini M., Ragadhita R., Nandiyanto A. B. D., Nugraha W. C., (2020) Adsorption characteristics of submicron porous carbon particles prepared from rice husk. *Journal of Engineering, Science and Technology,* 15, 022-031

Flora, S. J. S., Mittal, M., Mehta, A., (2008). Heavy metal induced oxidative stress & its possible reversal by chelation therapy. *Indian Journal of Medical Research*, *128*(4), 501.

Hamidah I., Sriyono S., Hudha M. N., (2020) A Bibliometric analysis of Covid-19 research using VOSviewer. *Indonesian Journal of Science and Technology,* 5(2), 34-41. doi: https://doi.org/10.17509/ijost.v5i2.24522

Hammouti B., (2010). Comparative bibliometric study of the scientific production in Maghreb countries (Algeria, Morocco and Tunisia) North Africa 1996-2009, *J. Mater. Environ. Sci.* 1 N°2, 70-76.

Hirawan D., Oktafiani D., Fauzan T. A., Luckyardi S., Jamil N., (2022) Research trends in farming system soil chemical: A bibliometric analysis using vosviewer. *Moroccan Journal of Chemistry,* 10(3), 576-590. doi: https://doi.org/10.48317/IMIST.PRSM/morjchem-v10i3.33145

Kurniati P. S., Saputra H., Fauzan T. A., (2022) A bibliometric analysis of chemistry industry research using vosviewer application with publish or perish. *Moroccan Journal of Chemistry,* 10(3), 428-441. doi: https://doi.org/10.48317/IMIST.PRSM/morjchem-v10i3.33061

Kwon S. Y., Blum J. D., Yin R., Tsui M. T.-K., Yang Y. H., Choi J. W., (2020) Mercury stable isotopes for monitoring the effectiveness of the Minamata Convention on Mercury. *Earth-Science Reviews, 203*, 103111. doi: https://doi.org/10.1016/j.earscirev.2020.103111

Lrhoul N., El Assaoui N., Turki H., (2021). Mapping of water research in Morocco: A scientometric analysis, *Materials Today: Proceedings,* 45, Part 8, 7321-7328, https://doi.org/10.1016/j.matpr.2020.12.1222.

Luckyardi S., Soegoto E. S., Jumansyah R., Dewi N. P., Mega R. U., (2022) A bibliometric analysis of climate smart agriculture research using vosviewer. *Moroccan Journal of Chemistry,* 10(3), 488-499. doi: https://doi.org/10.48317/IMIST.PRSM/morjchem-v10i3.33077

Mantey J., Nyarko, K. B., Owusu-Nimo, F., Awua, K. A., Bempah, C. K., Amankwah, R. K., Appiah-Effah, E.,

(2020). Mercury contamination of soil and water media from different illegal artisanal small-scale gold mining operations (galamsey). *Heliyon*, 6(6), e04312. doi: https://doi.org/10.1016/j.heliyon.2020.e04312

Maryanti R., Nandiyanto A. B. D., Manullang T. I. B., Hufad A., Sunardi S., (2020) Adsorption of dye on carbon microparticles: physicochemical properties during adsorption, adsorption isotherm and education for students with special needs. *Sains Malaysiana, 49*(12), 2949-2960. doi: http://dx.doi.org/10.17576/jsm-2020-4912-09

Moody K. H., Hasan K. M., Aljic S., Blakeman V. M., Hicks L. P., Loving D. C., Moore M. E., Hammett B. S., Silva-González M., Seney C. S., (2020) Mercury emissions from Peruvian gold shops: Potential ramifications for Minamata compliance in artisanal and small-scale gold mining communities. *Environmental Research, 182*, 109042. doi: https://doi.org/10.1016/j.envres.2019.109042

Morante-Carballo F., Montalván-Burbano N., Aguilar-Aguilar M., Carrión-Mero P., (2022) A bibliometric analysis of the scientific research on artisanal and small-scale mining. International *Journal of Environmental Research and Public Health, 19*(13), 8156. doi: https://doi.org/10.3390/ijerph19138156

Mudzakir A., Rizky K. M., Munawaroh H. S. H., Puspitasari D., (2022) Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis. *Indonesian Journal of Science and Technology, 7*(2), 291-310. doi: https://doi.org/10.17509/ijost.v7i2.50800

Mulyawati I. B., Ramadhan D. F., (2021) Bibliometric and visualized analysis of scientific publications on geotechnics fields. *ASEAN Journal of Science and Engineering Education, 1*(1), 37-46. doi: https://doi.org/10.17509/ajsee.v1i1.32405

Nandiyanto A. B. D., (2020) Isotherm adsorption of carbon microparticles prepared from pumpkin (Cucurbita maxima) seeds using two-parameter monolayer adsorption models and equations. *Moroccan Journal of Chemistry, 8*(3), 2745-2761.

Nandiyanto A. B. D., Al Husaeni D. F., (2021) A bibliometric analysis of materials research in Indonesian journal using VOSviewer. *Journal of Engineering Research*

Nandiyanto A. B. D., Al Husaeni D. F., Ragadhita R., (2023) Bibliometric data analysis of research on resin-based brake-pads from 2012 to 2021 using VOSviewer mapping analysis computations. *ASEAN Journal for Science and Engineering in Materials, 2*(1), 35-44

Nandiyanto A. B. D., Al Husaeni D., (2022) Bibliometric analysis of engineering research using vosviewer indexed by googles scholar. *Journal of Engineering Science and Technology, 17*(2), 883-894

Nandiyanto A. B. D., Al Husaeni D., Al Husaeni D., (2021) A bibliometric analysis of chemical engineering research using vosviewer and its correlation with covid-19 pandemic condition. *Journal of Engineering Science and Technology, 16*(6), 4414-4422

Nandiyanto A. B. D., Biddinika M. K., Triawan F., (2020) How bibliographic dataset portrays decreasing number of scientific publications from Indonesia. *Indonesian Journal of Science and Technology, 5*(1), 154-175

Nandiyanto A. B. D., Girsang G. C. S., Maryanti R., Ragadhita R., Anggraeni S., Fauzi F. M., Sakinah P., Astuti A. P., Usdiyana D., Fiandini M., (2020) Isotherm adsorption characteristics of carbon microparticles prepared from pineapple peel waste. *Communications in Science and Technology, 5*(1), 31-39

Nandiyanto A. B. D., Hofifah S. N., Inayah H. T., Putri S. R., Apriliani S. S., Anggraeni S., Usdiyana D., Rahmat A., (2021) Adsorption isotherm of carbon microparticles prepared from pumpkin (Cucurbita maxima) seeds for dye removal. *Iraqi Journal of Science*, 1404-1414

Nandiyanto A. B. D., Ragadhita R., Fiandini M., Al Husaeni D. F., Al Husaeni D. N., Fadhillah F., (2022) Domestic waste (eggshells and banana peels particles) as sustainable and renewable resources for improving resin-based brakepad performance: Bibliometric literature review, techno-economic analysis, dual-sized reinforcing experiments, to comparison. *Communications in Science and Technology, 7*(1), 50-61

Nandiyanto A. B. D., Ragadhita R., Yunas J., (2020) Adsorption isotherm of densed monoclinic tungsten

trioxide nanoparticles. Sains Malaysiana, 49(12), 2881-2890
Nordin N. A. H. M., (2022a) A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation. *Indonesian Journal of Teaching in Science, 2*(2), 127-138
Nordin N. A. H. M., (2022b) Correlation between process engineering and special needs from bibliometric analysis perspectives. *ASEAN Journal of Community and Special Needs Education, 1*(1), 9-16
Nugraha A. S., (2022) Bibliometric analysis of magnetite nanoparticle production research during 2017-2021 using Vosviewer. *Indonesian Journal of Multidiciplinary Research, 2*(2), 327-332. doi: https://doi.org/10.17509/ijomr.v2i2.43331
Nugraha W. C., Jeong H., Dinh Q. P., Ishibashi Y., Arizono K., (2021) Effective removal of mercury (Hg) from sediment by acid extraction. *IOP Conference Series: Earth and Environmental Science, 909*, 012017. doi: https://doi.org/10.1088/1755-1315/909/1/012017/meta
Nugraha W. C., Jeong H., Phan Dinh Q., Ishibashi Y., Arizono K., (2022) Combination of vortex agitation and ultrasonic irradiation for mercury removal from sediment by acid extraction. *Bulletin of Environmental Contamination and Toxicology, 108*, 1118–1123. doi: https://doi.org/10.1007/s00128-022-03471-0
Palani D. M., Hamzah L. H., Hamasalim H. J., Mohammed H. N., Palani Z. M., (2022). Hygienic evaluation of heavy metals levels in meat tissues and fats after adding selenium and zinc. *Journal of Pharmaceutical Negative Results*, *13*(sp issue), 2033-2038. Doi: https://doi.org/ 10.47750/pnr.2022.13.S06.265
Palathoti S. R., Otitolaiye V. O., Mahfud R., Al Rawahi M., (2022) Impacts of mercury exposure on human health, safety and environment: Literature review and bibliometric analysis (1995 to 2021). *International Journal of Occupational Safety and Health, 12*(4), 336-352. doi: https://doi.org/10.3126/ijosh.v12i4.43125
Peplow D., Augustine S., (2014) Neurological abnormalities in a mercury exposed population among indigenous Wayana in Southeast Suriname. *Environmental Science: Processes and Impacts, 16*(10), 2415-2422. doi: https://doi.org/10.1039/C4EM00268G
Peplow D., Augustine S., (2014). Neurological abnormalities in a mercury exposed population among indigenous Wayana in Southeast Suriname. *Environmental Science: Processes & Impacts*, *16*(10), 2415-2422. doi: https://doi.org/ 10.1039/C4EM00268G
Prasetya A., Prihutami P., Warisaura A. D., Fahrurrozi M., Petrus H. T. B. M., (2020). Characteristic of Hg removal using zeolite adsorption and Echinodorus palaefolius phytoremediation in subsurface flow constructed wetland (SSF-CW) model. *Journal of Environmental Chemical Engineering, 8*(3), 103781. doi: https://doi.org/10.1016/j.jece.2020.103781
Qu R., Han G., Liu M., Li X., (2019). The mercury behavior and contamination in soil profiles in Mun River Basin, Northeast Thailand. *International Journal of Environmental Research and Public Health, 16*(21), 4131. doi: https://doi.org/10.3390/ijerph16214131
Ragadhita R., Nandiyanto A. B. D., (2021) .How to calculate adsorption isotherms of particles using two-parameter monolayer adsorption models and equations. *Indonesian Journal of Science and Technology, 6*(1), 205-234. doi: https://doi.org/10.17509/ijost.v6i1.32354
Ragadhita R., Nandiyanto A. B. D., (2022a). Computational bibliometric analysis on publication of techno-economic education. *Indonesian Journal of Multidiciplinary Research, 2*(1), 213-220
Ragadhita R., Nandiyanto A. B. D., (2022b). Curcumin adsorption on zinc imidazole framework-8 particles: Isotherm adsorption using Langmuir, Freundlich, Temkin, and Dubinin-Radushkevich models. *Journal of Engineering Science and Technology, 17*(2), 1078-1089.
Ramadhan D. F., Fabian A. M., Saputra H. M., (2023). Dental suction aerosol: Bibliometric analysis. *ASEAN Journal of Science and Engineering, 2*(3), 295-302. doi: https://doi.org/10.17509/ajse.v2i3.50658
Reis A. T., Davidson C. M., Vale C., Pereira E., (2016). Overview and challenges of mercury fractionation and speciation in soils. *TrAC Trends in Analytical Chemistry, 82*, 109-117. doi: https://doi.org/10.1016/j.trac.2016.05.008
Riandi R., Permanasari A., Novia N., (2022) Implementation of biotechnology in education towards green

chemistry teaching: A bibliometrics study and research trends. *Moroccan Journal of Chemistry, 10*(3), 417-427. doi: https://doi.org/10.48317/IMIST.PRSM/morjchem-v10i3.33060

Riaz A., Khan S., Muhammad S., Liu C., Shah M. T., Tariq M., (2018) Mercury contamination in selected foodstuffs and potential health risk assessment along the artisanal gold mining, Gilgit-Baltistan, Pakistan. *Environmental Geochemistry and Health, 40*(2), 625-635. doi: https://doi.org/10.1007/s10653-017-0007-6

Sandeep, G., Vijayalatha, K. R., Anitha, T., (2019). Heavy metals and its impact in vegetable crops. *Int J Chem Stud*, *7*(1), 1612-1621.

Saputra H., Albar C. N., Soegoto D. S., (2022) Bibliometric analysis of computational chemistry research and its correlation with Covid-19 pandemic. *Moroccan Journal of Chemistry, 10*(1), 037-049. doi: https://doi.org/10.48317/IMIST.PRSM/morjchem-v10i1.31723

Seccatore J., Veiga M., Origliasso C., Marin T., De Tomi G., (2014) An estimation of the artisanal small-scale production of gold in the world. *Science of the Total Environment, 496*, 662-667. doi: https://doi.org/10.1016/j.scitotenv.2014.05.003

Setiyo M., Yuvenda D., Samuel O. D., (2021) The concise latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis. *Indonesian Journal of Science and Technology, 6*(3), 469-490. doi: https://doi.org/10.17509/ijost.v6i3.38430

Shidiq A. P., (2021) A bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSviewer. *ASEAN Journal of Science and Engineering, 3*(1), 31-38. doi: https://doi.org/10.17509/ajse.v3i1.43345

Shidiq A. S., Permanasari A., Hernani S. H., (2021) The use of simple spectrophotometer in STEM education: A bibliometric analysis. *Moroccan Journal of Chemistry, 9*(2), 290-300. doi: https://doi.org/10.48317/IMIST.PRSM/morjchem-v9i2.27581

Soegoto H., Soegoto E. S., Luckyardi S., Rafdhi A. A., (2022) A bibliometric analysis of management bioenergy research using VOSviewer application. *Indonesian Journal of Science and Technology, 7*(1), 89-104. doi: https://doi.org/10.17509/ijost.v7i1.43328

Sudarjat H., (2023) Computing bibliometric analysis with mapping visualization using vosviewer on "pharmacy" and "special needs" research Data in 2017-2021. *ASEAN Journal of Community and Special Needs Education, 2*(1), 1-8

Tabatabaei-Malazy O., Ramezani A., Atlasi R., Larijani B., Abdollahi M., (2016) Scientometric study of academic publications on antioxidative herbal medicines in type 2 diabetes mellitus. *Journal of Diabetes and Metabolic Disorders, 15*(1), 1-8. doi: https://doi.org/10.1186/s40200-016-0273-3

Tahamtan I., Safipour Afshar A., Ahamdzadeh K., (2016) Factors affecting number of citations: a comprehensive review of the literature. *Scientometrics, 107*(3), 1195-1225. doi: https://doi.org/10.1007/s11192-016-1889-2

Tayrab E., (2017). Thyroid function in sudanese gold miners with chronic mercury exposure. *Age (years)*, *30*, 28-1.

Veiga M. M., Maxson P. A., Hylander L. D., (2006) Origin and consumption of mercury in small-scale gold mining. *Journal of Cleaner Production, 14*(3-4), 436-447

Veiga, M. M., Fadina, O., (2020). A review of the failed attempts to curb mercury use at artisanal gold mines and a proposed solution. *The Extractive Industries and Society*, *7*(3), 1135-1146. Doi: https://doi.org/10.1016/j.exis.2020.06.023

Wiendartun W., Wulandari C., Fauzan J., Hasanah L., Nugroho H. S., Pawinanto R., Mulyanti B., (2022) Trends in research related to photonic crystal (PHC) from 2009 to 2019: A bibliometric and knowledge mapping analysis. *Journal of Engineering Science and Technology, 17*(1), 0343-0360

Wilhelm S. M., Bloom N., (2000) Mercury in petroleum. *Fuel Processing Technology, 63*(1), 1-27. doi: https://doi.org/10.1016/S0378-3820(99)00068-5

Wirzal M. D. H., Putra Z. A., (2022) What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using vosviewer indexed by google scholar?

Indonesian Journal of Community and Special Needs Education, 2(2), 103-110. doi: https://doi.org/10.17509/ijcsne.v2i2.44581

Wong S. L., Nyakuma B. B., Nordin A. H., Lee C. T., Ngadi N., Wong K. Y., Oladokun O., (2021) Uncovering the dynamics in global carbon dioxide utilization research: a bibliometric analysis (1995–2019). *Environmental Science and Pollution Research, 28*(11), 13842-13860. doi: https://doi.org/10.1007/s11356-020-11643-w

Wong S. L., Nyakuma B. B., Wong K. Y., Lee C. T., Lee T. H., Lee C. H., (2020) Microplastics and nanoplastics in global food webs: A bibliometric analysis (2009–2019). *Marine Pollution Bulletin, 158*, 111432. doi: https://doi.org/10.1016/j.marpolbul.2020.111432

Yang L., Zhang Y., Wang F., Luo Z., Guo S., Strähle U., (2020) Toxicity of mercury: Molecular evidence. *Chemosphere, 245*, 125586. doi: https://doi.org/10.1016/j.chemosphere.2019.125586

Yoshimura A., Suemasu K., Veiga M. M., (2021) Estimation of mercury losses and gold production by artisanal and small-scale gold mining (ASGM). *Journal of Sustainable Metallurgy, 7*(3), 1045-1059. doi: https://doi.org/10.1007/s40831-021-00394-8

Zolnikov T. R., Ortiz D. R., (2018) A systematic review on the management and treatment of mercury in artisanal gold mining. *Science of the Total Environment, 633*, 816-824. doi: https://doi.org/10.1016/j.scitotenv.2018.03.241

Zuas O., Elishian C., Darmayanti N. T. E., Budiman H., Yaumidin U. K., (2021) Research on contamination of foods with mercury mining: A ten-year (2011-2020) bibliometric analysis. *IOP Conference Series: Earth and Environmental Science, 926*, 012058. doi: https://doi.org/10.1088/1755-1315/926/1/012058/meta

Zupic I., Čater T., (2015) Bibliometric methods in management and organization. *Organizational Research Methods, 18*(3), 429-472. doi: https://doi.org/10.1177/1094428114562629

(2023) ; https://revues.imist.ma/index.php/morjchem/index