Research on Contamination of Foods with Mercury Mining: A Ten-Year (2011-2020) Bibliometric Analysis

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Abstract. The first study on bibliometric network analysis of research on contamination of foods with mercury (Hg) mining is presented. The Hg mining has been reported as the primary source of toxic Hg contamination of foods. The living population’s exposure to Hg is highly associated with the consumption of Hg-contaminated foods and water. This study aims to explore the global scientific literature to gain insight into how the scientific literature addresses contamination of foods with Hg mining using bibliometric network analysis. The study was conducted on 319 documents from publications indexed in the Scopus database from 2011 to 2020. We collected reviewed documents using various techniques to analyze this issue, including general statistics, bibliometrics, and analytics. According to analysis results, several significant findings were found as follows. The co-authorship network demonstrates the relationship among authors and countries regarding contamination of foods with Hg mining. Co-authorship authors and country analysis indicate that “Chinese authors” and “the Chinese Academic of Sciences” are the first among the most influential authors and institution, respectively. Moreover, from systematic visualization of co-occurrence keywords and clustering analyses, six major clusters were reviewed and have been identified as potential opportunities for future research.

1. Introduction
Artisanal and small-scale gold mining (ASGM) is a simple method used to separate gold from the ore [1]. The ASGM is generally carried out by individual miners or small companies with limited capital investment and production quantities [2]. The ASGM activities use mercury (Hg) to extract gold from mining ore through an amalgamation process which the end of this process produces Hg contaminants [1, 3]. The ASGM sector is known as the most significant contributor to Hg contaminants in the environment, which have implications for disrupting the quality of the water and soil, leading to ecosystem damage [3-5].

Due to its high toxicity, mobility, and prolonged residence time, the Hg is recognized as a priority hazardous substance by the Agency for Toxic Substances and Disease Registry that is harmful to humans and wildlife [6, 7]. Human exposure to Hg is mainly through the food chain and inhalation [6, 8]. When Hg from mining activities is discharged into the environment, it may convert to organic mercury species (methylmercury/Me-Hg). Some biota in aquatic ecosystem such as fish and shellfish may be contaminated with this Hg, and it will be dangerous for health if they are consumed by human [5, 6, 9,
Humans may be exposed to Hg via inhaling vapor or air containing Hg during the mining process. Metallic (Hg$^0$) and Me-Hg are the most toxic species, and their effects on humans is dependent on the duration of exposure, dosage, and the condition of the human being exposed. Awareness of the dangers of Hg began in the Minamata case when Me-Hg was released into the sea bay in Minamata, Japan, in the 1950s, which caused poisoning in residents who consumed seafood from the bay [11]. Another case was reported in Amazonian communities that had been poisoned by Me-Hg when they consumed fish and water contaminated with Hg from gold mining in the Amazon basin [12]. Several cases of Hg contamination in water environment and foods have also been reported in several countries such as the United States [13], Pakistan [14], Indonesia [15], Ghana [16], Suriname [17], and Slovakia [18].

Bibliometric analysis (BA) is a systematic review method used to identify research trends and current issues based on the history of a publication to obtain an overview of a research field to produce results with more in-depth content analysis. In a practical application of BA, the distribution pattern of articles related to a topic, field, author, institution, or country is presented quantitatively using statistical methods [19-21]. This method establishes an objective criterion that is used as the basis for selecting, reviewing, and tracking published research. It makes the bibliometric analysis valuable for assessing the scientific quality, productivity, and influence of the topic being studied [21]. The BA has several advantages that include (i) providing information for certain thematic areas; (ii) assessing the quality and scientific developments for a particular topic; (iii) providing information for the sources of research funding; (iv) comparing research results among various institutions; (v) documenting the occurrence of research changes, and predicting the potential progress of a scientific field by identifying emerging areas of research focus [22].

This study uses the bibliometric method to analyze literature related to food contamination by Hg mining. The specific objectives of this research are to gain information on the document growth during 2011-2020, disciplines, the most productive authors and institutions, collaborations among authors and countries, and cluster analysis. In addition, this study also presents a review the prospects related to the topic of the study.

2. Methodology

Figure 1 displays a detailed process of bibliometric analysis.

**Figure 1.** Methodology

2.1. Data sources and search strategy

The articles used in this study were obtained from the Scopus database and were limited to published documents related to research on food contamination by Hg mining in 2011-2020. The keywords used in the search engine of the Scopus database were set to (titles, abstracts, and keywords) as follows "mercury" AND "mining" AND "food" OR "foods". Only English documents with document types in the form of journals, conference proceedings, and reviews were involved.
2.2. Pre-analysis and data cleansing
In general, documents collected from various databases cannot be analyzed directly because a possible topic is indirect to the theme understudied. Therefore, pre-analysis and data cleansing steps are required [23]. Pre-analysis data was carried out by reading the titles, abstracts, and keywords of all documents and discarding unrelated one. Data cleansing was conducted by observing all keywords, affiliations, author's name, and country of each article for any possible errors such as erroneous entries and spelling errors. The cleansed data was then constructed into a file called the thesaurus file [24].

2.3. Data analysis and visualization
The documents obtained were processed by an excel program using general statistics. We did descriptive analysis by considering the following indicators, i.e., trend of documents growth, disciplines (subject area), the most productive authors, and institutions. For network analysis and visualization, the documents from Scopus database were exported in the form of comma-separated values (CSV) files. This file was then run into a VOSviewer v.1.6.14 program [25]. To analyze the collaboration trend among authors and countries, we used the co-authorship indicators. The main areas of research activity on food contamination by Hg mining and reflection of the content of some selected documents were analyzed using the co-occurrence of the author keywords.

3. Results and discussion
3.1. Summary of statistics
Scopus is currently the largest citation database resource for peer-reviewed scientific literature and a high-quality data source. The Scopus database has been widely used in many bibliometric analysis studies [24]. Currently, the indexed content scope of Scopus has reached more than 20,000 journals by more than 5000 publishers worldwide.

By identifying author keywords, 341 documents were published during the period of 2011-2020. Toward the initial 341 papers, a selection process was carried out by reading the title, abstract, and keywords to eliminate articles unrelated to "mercury mining". It remained 319 documents, which met the criteria for the next analysis.

The following process is keyword screening because there is a possibility that the data obtained from the searching process contains several documents with misspellings or writing differences. Some errors found in this stage include a keyword "contamination" that is also written as "contaminaction." Thus, for the cleansing purpose, they were written as "contamination." The difference in writing occurs in the keywords "gold-mining" and "gold mining" and "Au mining" so that to write uniformity, in the thesaurus file, they were written as "gold mining."

In addition, some following statistic data were obtained. Of 319 documents were written by 1406 authors using 759 keywords. The number of authors’ affiliation are 948 located in 79 countries. The 319 articles were published in 143 journals and have been totally cited 7540 times.

3.2. Descriptive analysis
3.2.1. Document growth and subject area
The number of published documents is an essential indicator in evaluating the development of a particular scientific field [26]. Figure 2a shows an annual growth of articles related to foods contamination by Hg mining between 2011 and 2020. From Figure 2a, it can be seen that the number of documents gradually increases annually, indicating that foods contamination by Hg mining is still an attractive topic. The Hg (in the form of its metallic and organic species) is very toxic, and exposure to Hg can induce an unbalance of ecosystems and human health. Thus, collected data on the research of food contamination by Hg mining is essential for the government to make policies related to preventing and mitigating the impact of Hg contamination on food.

Discipline (subject areas) of a published document plays a vital role because it can provide an overview related to the classification of the scientific field of the subject under study. Figure 2b shows
the distribution of subject areas for published documents on foods contamination by Hg mining. However, it is worth noting that subject areas classification based on the Scopus database is intertwined, meaning that each document can be classified into several disciplines. The consequence is the number of collected documents would be larger than 319. In addition, the most published documents (Figure 2b) are in the subject area of "environmental science," then followed by "medicine" and "agricultural and biological science." It indicates that applying multidiscipline in conducting research on foods contamination by Hg mining can be a good approach.

**Figure 2.** Annual growth (a) and subject area (b) of published documents in foods contamination by Hg mining (2011-2020)

3.2.2. Top authors and institutions

For a researcher, the number of publications can be used as a measure of success and achievement in the academic field [27]. Besides, publications may increase credibility and open up opportunities for their expertise to be better known and recognized. Figure 3a shows the top 10 productive authors in publishing articles related to foods contamination by Hg mining.

**Figure 3.** Top 10 most productive authors (a) and institutions (b) on the publishing of articles in foods contamination by Hg mining (2011-2020)

The first three productive authors were Xinbin Feng, Guangle Qiu, and Ping Li. Those authors were affiliated with State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, P. R. of China. The next positions were occupied by Milena Horvat (Department of Environmental Sciences, Jožef Stefan Institute, Slovenia), Heileen Hsu-Kim (Civil and Environmental Engineering, Duke University, USA), Sergi Díez (Department of Environmental Chemistry, Institute of Environmental Assessment and Water Research, Spain), Collin A. Eagles-Smith (US Geological Survey, USA), and Christopher WN Anderson (Soil and Earth Sciences, Institute of Agriculture and Environment, Massey University, New Zealand). Moreover, Figure 3b shows the top 10 productive institutions in publishing scientific documents related to foods contamination by Hg mining. The Chinese Academy of Science occupied the first to third positions with a total of 93 articles.
3.3. Bibliometric Analysis
3.3.1. The most collaborative authors and countries

Co-authorship networks, in general, can be used as an indicator to explore research collaboration networks among authors, among institutions, or among countries [28]. Weak co-authorship networks imply a lack of communication, cooperation, and low productivity. Besides, a document produced through scientific collaboration can have a higher impact and tends to be cited more [29].

Figure 4 shows a network of co-authorship authors and countries on research related to foods contamination by Hg mining. For visualization purposes, the minimum number of articles for each author are 5 articles. With this threshold, of the 1406 authors, there are 19 remaining who meet the threshold with 16 authors having the largest connections (Figure 4a). Map visualization (Figure 4a) shows that there are 5 clusters and the first position for each cluster is occupied by Liang, L., Feng, X., Qiu, G., Xu, X., and Zhang, C. The large size of the interlink between authors indicates the level of strength of their collaboration and knowledge sharing. On the other hand, the small size of the interlink indicates a weak collaboration.

![Figure 4a](image1.png)  ![Figure 4b](image2.png)

Figure 4. Visualization map of co-authorship: (a) authors and (b) countries related to foods contamination by Hg mining (2011-2020), showing the most significant co-authorship in their cluster (dotted circle lines).

Figure 4b shows the collaboration network between the countries of origin regarding research related to foods contamination by Hg mining. For visualization purposes, the minimum number of articles for each author are 4 articles, with the maximum number of authors for each article are 25 people. With the criteria given, out of 71 countries, 29 countries have met the requirements, with 28 countries having the largest connections. The visualization results produce 4 clusters with the first position for each cluster occupied by Denmark, Spain, United States, and Indonesia. Information related to cooperation between the author's countries of origin allows the author to obtain information for future international cooperation. Furthermore, from the size of the interlink, it can be seen the strength of cooperation between countries. From Figure 4b, it is known that the United States is a country that occupies the position as a country with the best level of collaboration and has a strong network with Canada, P. R. of China, UK, and Peru. The second position for collaboration is occupied by P. R. of China who has strong cooperation with Canada and New Zealand.

3.3.2. Cluster analysis

The keywords of a scientific documents displayed by the author is an important indicator to find out the main areas of research and reflect the content of document [30]. In bibliometric analysis, the linkage of keywords through a network map can provide an accurate picture of scientific knowledge output by showing patterns, relationships, and intellectual organization of the field of research activity [31].

The construction of the visualization map was done by running the obtained CSV file into the VOSviewer program [25]. In this study, to get a map of the occurrence of foods contamination by Hg mining (Figure 5), it was applying keyword restriction criteria with keywords that had been occurred at least 5 times. Under these criteria, 39 keywords met the requirements and generated 6 clusters. A cluster
is a group of keywords that have homogeneous entities with similar attributes. From Figure 5, it is has been known that the node and the connecting line of each node show different in size, indicating differences in occurrence and relationships among keywords. A discussion of each cluster is presented below.

Figure 5. Map network co-occurrence keyword related to foods contamination by Hg mining (2011-2020), showing the most occurrence keyword in their cluster (dotted circle lines).

**Cluster 1.** The first category for the cluster analysis (red) involves studying the bioaccumulation of trace elements of heavy metals in food. Documents in this cluster discuss heavy metal pollution such as cadmium (Cd), lead (Pb), arsenic (As), and Hg due to mining activities, which have an impact on increases the level of environment pollution [32, 33]. Environment (soil and water) contaminated with heavy metals can be a pathway for the entry of these heavy metals into the food web through soil plants or water-fish transfers [34, 35]. These heavy metals are bioaccumulated in plants or fish which if it consumed by humans may pose a threat to health [4, 36].

**Cluster 2.** The green indicates the second category for the cluster analysis. This cluster involves some studies related to the concentrations of trace toxic and essential elements in fish obtained from waters in the ASGM area. Fish is one of the sources of the fisheries industry that contributes to the social and economic development in many countries worldwide. However, consuming fish obtained from contaminated waters around the ASGM may impact on health [37, 38]. In fish biology tissue, Hg can be converted by microorganisms into the most toxic Hg species i.e., MeHg [9, 39]. However, current studies reported that the presence of metal selenium (Se) in fish could increase the demethylation process of MeHg into inorganic Hg (I-Hg). It could lead to reduce the bioaccumulation of MeHg and its effects [40].

**Cluster 3.** The third category (blue) for cluster analysis involves a study regarding the levels of Hg metal contamination in sediments. The MeHg, with its persistence property, can stay in sediments for a long time. The level of Hg contamination in sediments can be evaluated using the geo-accumulation index (Igeo) method [41, 42]. The Igeo is a common method used in determining the level of heavy metals contamination in sediments [41, 43]. It has been reported that the concentration of Hg in sediment may timely changes in concentration, and favorable geochemical conditions of sediment could facilitate the processes of Hg methylation and Hg transfer to the food chain. Thus, it can increase Hg’s potential in threatening the health of humans and aquatic organisms [10].

**Cluster 4.** The fourth category for the analysis cluster (brown) is related to epidemiology studies of toxic metals on populations living in the ASGM areas. Health risk studies indicate that the Hg produced by gold mining may impact on indigenous communities around the mining [44-46]. Children or communities living along the ASGM site might be at risk of Hg chronic exposure due to consuming fish from polluted water [5, 46, 47]. In addition to fish consumption, consuming rice (Oryza sativa L.) is another source of Hg exposure for the communities in the terrestrial ecosystem of mining areas because the rice could act as a good accumulator for MeHg [48-51].

**Cluster 5.** The fifth category formed for the analysis cluster (pink) involves biomonitoring of Hg metal contamination in humans and the environment. Utilization of Hg in the ASGM produces waste-containing Hg usually discharged into tributaries or water systems [52, 53]. It is the main source of Hg
exposure for the community and children who live in the ASGM area. The main route of public exposure is through the food chain, namely by consuming fish and seafood originating from waters contaminated with heavy metals, including Hg [54, 55]. Currently, studies of exposure and risk of heavy metals to human health and the environment mostly use a biomonitoring approach that uses blood and hair as biomarkers [56, 57]. The hair sample is more studied than blood because hair is a non-invasive matrix and is easy to sample [58-60].

Cluster 6. The sixth category for the analysis cluster (turquoise) is related to the study on impact of gold mining activities. The studies mainly were focused on the levels of Hg content in water and food consumed by humans. A study on heavy metal pollution in the mining environment is generally conducted by assessing pollutant targets on soil, sediment, and air [61-66]. Other studies used food and water as samples. The studies reported that high Hg concentrations were found in water and some biota that residents around the ASGM area generally consumed, implying that a long exposure of Hg to the community may risk to the health [67-69].

4. Conclusions and Future Direction
This study carried out a bibliometric analysis of food contamination by Hg mining with documents obtained from the Scopus database using the VOSviewer software. The number of publications shows a steady increase during the period of 2011-2020. Of all the disciplines, the first rank is environmental science, with a contribution of 239 articles. Xinbin Feng from the State Key Laboratory of Environmental Geochemistry of the Institute of Geochemistry, Chinese Academy of Sciences, the People's Republic of China was the most prolific author with 24 articles. The most productive institution was also placed by the Chinese Academy of Science, with 93 articles. Research collaboration tends to occur among researchers in the same country, indicating that the cooperation of researchers between countries needs to be improved. The researcher from the United States was well known as the best level of collaboration. The most frequent keyword related to the study of food contamination by Hg mining is heavy metals, methyl mercury, mercury, bioaccumulation, gold mining, and health risks. Lastly, it can be concluded from the cluster analysis that future research may take several fascinating topics in this direction. It includes (i) the bioaccumulation of trace elements in food tissues; (ii) concentrations of toxic and essential trace elements in fish from waters near mining areas, (iii) levels of Hg metal contamination in sediments, epidemiological studies of toxic metal on populations living in mining areas; (iv) biomonitoring of Hg metal contamination in humans and the environment; (v) and studies of the impact of mining activities (gold) on Hg levels in water and food.

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