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Original article

Potential implications of gold-mining activities on some environmental components: A global assessment (1990 to 2018)

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ABSTRACT

This study analysed 115 Gold Mining Impact (GMIs) research articles published in Web of Science (WOS) with the highest total lifetime citations and citations per year by summarising the trends, search terms, keywords, most productive authors and their countries based on the area of investigation. To assess the studies that have been undertaken on GMIs, we used "Gold Mining Impacts" as the search term for the studies published from 1990 to 2018 using bibliometric innovative techniques. The results revealed an annual growth rate of about 11.3% which connotes that research on GMIs has been increasing over time during the period of study. However, the research output on GMIs fluctuated during the survey period, peaking in 2018 accounting for 14.95% (13/115) of the total, followed by 2015 with 10 research articles (11.5%) during the same period. Findings from this study also revealed the top 20 most productive countries with USA (21, 24.15%), South Africa (12, 13.8%) and Canada (8, 9.2%) ranking first, second and third respectively. Most studies on GMIs were from developed nations, while a few came from developing countries. The United States of America and South Africa had the highest research articles published on GMIs despite their ranking in gold production.

1. Introduction

Globally, the environmental protection legislation aimed at monitoring, managing and protecting the ecosystem and its environs. Study has shown that natural and human activities contribute immensely to environmental health degradation (Guerry et al., 2015). These activities which include mining operation, deforestation, agricultural expansion, mineral extraction and urban development have severe consequences such as global biodiversity loss, degradation of ecosystem services and carbon budget (Tegegne et al., 2016). Human activities including gold mining causes extensive damages to natural landscape, contaminates water and contributes to the destruction of ecosystems (Palacios-Torres et al., 2020). Substances such as mercury, cyanide and other toxic substances are regularly released into the environment through gold mining activities (Lee and Ilyas, 2018).

Gold mining and other mining activities globally, especially in developing nations, remain controversial due to evidence of a noticeable impact on the local climate, natural environment and socio-economic status of the local population. Mining operations and its waste disposal methods are considered one of the main causes of environmental health degradation (Spiegel et al., 2018; Orimoloye et al., 2018, 2019). Mine tailings are often toxic, and if not contained, can be harmful to human and environmental health. It is therefore important to assess the scale of problems associated with mining and other practices that have been studied and to visualised research that has been done over the years, both academic studies and reports, to deal with these gaps of knowledge. One of the techniques or approaches that can be used to address these gaps is by visualising the effectiveness of the studies conducted on GMIs using scientometric analysis. Hence, this study aims to investigate the potential impact of gold mining activities on environmental components by using scientometric methods to identify keywords in relation to two main factors, most productive authors and most collaborating countries, then determine the association strength between them during the study period. The analysis will further characterise the intellectual dynamics by visualising and identifying the impact, evolution of the co-citation network, collaboration network and trends on GMIs research. This study did not only help in identifying existing research on GMIs

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on the environment but also showed the ongoing global research shifts.

2. Methodology

2.1. Data collection and methods

This study used published studies on GMIs retrieved from the Web of Science (WOS) database on January 5, 2019. In order to assess the research studies that have been on GMIs, "Gold Mining Impacts" was used as the search term for the studies published between January 1990 and December 2018 (Table S1), using a title-specific search for quick visibility and easy retrieval. The title search was used because of its efficiency as stated by Aleixandre-Benavent et al. (2017) who opined that a title-specific search has the merits of minimal loss, significant recovery and sensitivity over other types of searches such as a topic, field or author search. Gold production data between 2012 and 2016 were obtained from the World Mining database (http://www.wmc.org.pl/?q = node/49).

3. Data processing and analysis

This study evaluated data acquired for bibliometric analysis using RStudio v.3.4.1 software with bibliometrix R-package. Data were imported into RStudio and converted to a bibliographic data frame and normalised for duplicate matching (Aria and Cuccurullo, 2017, Ekundayo and Okoh, 2018). Author names, author keywords (DE), and keywords-plus (ID) were also extracted for visualisation. Author names were extracted twice as two different sets (A and B).

4. Results

The attributes of the 115 articles published on GMIs studies within the survey period are presented in Table S1. The study involved an analysis of 408 authors with 436 author appearances, with 0.28 article/author (3.55 authors/article), 3.79 co-authors/article, and a collaboration index of 4.2. An average annual percentage growth rate of 11.28% citations/article was recorded during the study period. The scientific output related to GMIs research by Lotka's law (Nicholls, 1989) showed a beta coefficient and constant of 2.50 and 0.45 respectively, with a Kolmogorov-Smirnoff goodness-of-fit of 0.9859036 (P = 0.47, two-sample *t*-test). Published research on GMIs between 1990 and 2018 with the annual article production is presented in Table S4.

Published studies as well as average total citations per year of GMIs related research are shown in Fig. 1. The annual growth rate was 11.3, which connotes that research on GMIs has been increasing over time especially during the period of study. Research output fluctuated during the survey period, peaking in 2018 which accounted for 14.95% (13/115) of the total, followed by year 2015 with 10 research articles accounting for 11.5% (10/115) during the same period. The years 1990, 1995 and 1996 each have one article during the period, which connotes that these three years have the least research publication on GMIs. Similarly, the results from this study reveal the top 20 most productive authors between 1990 and 2018. Table S2 present the top 2 with three articles each during the period accounting for 2.61% of the total published research articles on GMIs. The second on the list was Akcil A. who published two research articles (1.7%) within the study period.

The information in Table S3 presents the top 20 manuscripts on GMIs per citations in the field during the period. Gibb H.'s 2014 "Health Perspective" ranked first with a total of 95 citations in his research on GMIs. Tarras-Wahlberg N. H.'s 2001 "Science of the Total Environment" ranked second with 79 citations, followed by Ogola et al. (2002) "Environ Geochem Health" with a total of 64 citations during the same period. Schueler V.'s 2011 "Ambio" and Marrugo-Negrete J.'s 2008 "Arch Environ Contam Toxicol" ranked fourth and fifth with 61 and 54 citations respectively during the period. Durand J. F.'s 2012 "J Afr Earth Sci", De Lacerda L.D.'s 2003 "Environ Geol" and Thorslund J.'s 2012 "J Environ Monit" ranked sixth, seventh and eighth with 52, 49 and 48 citations respectively. It is worth noting that the topmost active authors were affiliated with institutions located in developed and transition nations, including USA (n = 21), South Africa (n = 12), Canada (n = 8), Brazil (n = 7), United Kingdom (n = 6), Australia (n = 5), China (n = 5) and Colombia (n = 5), as presented in Table S7.

Furthermore, the average total citations of articles published per country varied from one country to the other during the study period. The information in Table S5 presents the top 20 citations per country of published research articles on GMIs. The results revealed that the most cited nations are developed nations, however, South Africa which is one of the transition nations ranked second among the most cited countries. The outstanding performance of South African research connotes that the country is doing well in supporting research in the field (Fedderke and Goldschmidt, 2015). The USA ranked first with 238 total citations and an average article citation of 11.33, followed by South Africa with 153 total citations and an average article citation of 12.57 on research studies published during the survey period. United Kingdom, Brazil, Colombia and Australia ranked third, fourth, fifth and sixth with total citations and average article citations of 137, 114, 97, 89 and 22.83, 16.26, 19.40, 17.80 respectively during the same period.

This study further revealed the most relevant sources for the research work published on GMIs between 1990 and 2018, as presented in Table S6. Ambio, Applied Geochemistry, Environmental Science and Pollution Research, and Journal of Geochemical Exploration ranked first with a total of three published research works on GMIs for each journal. Abstracts of papers of the American Chemical Society, Archives of Environmental Contamination and Toxicology, Chemosphere, Environmental Geology, and Environmental Science & Technology ranked second with a total number of articles published on GMIs during the survey period.

Table 1 and Fig. 1 show the most relevant keywords and authors coupling for the top 20 researchers respectively. The table also shows the most relevant keywords related to GMIs studies, including both author keywords (DE) and keywords-plus (ID). Author keywords (DE) and keywords-plus (ID) have seven keywords unique to both of them, which include mercury, sediments, acid mine drainage, methyl-mercury, heavy metals, Ghana and mine. The unique author keywords specifically describe the medium affected by mining activities and the means or factors involved in the process. Author keyword terms associated with the identification methods of GMIs include mercury (n = 14), mining (n = 12), heavy metals (n = 9), cyanide (n = 5), artisanal mining (n = 4), gold mine (n = 4), arsenic (n = 3), bioavailability (n = 3), environment (n = 3), gold (n = 3), methyl-mercury (n = 3), Ghana (n = 3), sediment (n = 3), acid mine drainage (n = 2) and biomagnification (n = 2).

The keyword analysis identified "sediment" in three (3.5%) and fourteen (16.1%) articles by author keyword and keyword-plus respectively, while "heavy metals" was found in nine (10.35%) and ten (11.5%) articles by keyword and keyword-plus respectively during the same period. "Acid mine drainage" was identified in two (2.3%) and six (6.9%) articles by keyword and keyword-plus respectively in the GMIs research field. This analysis connotes that studies on GMIs emphasised these environmental-related issues several times, an indication that gold mining activities have contributed to environmental issues, water and air pollution, natural soil alteration and environmental contamination (Fashola et al., 2016).

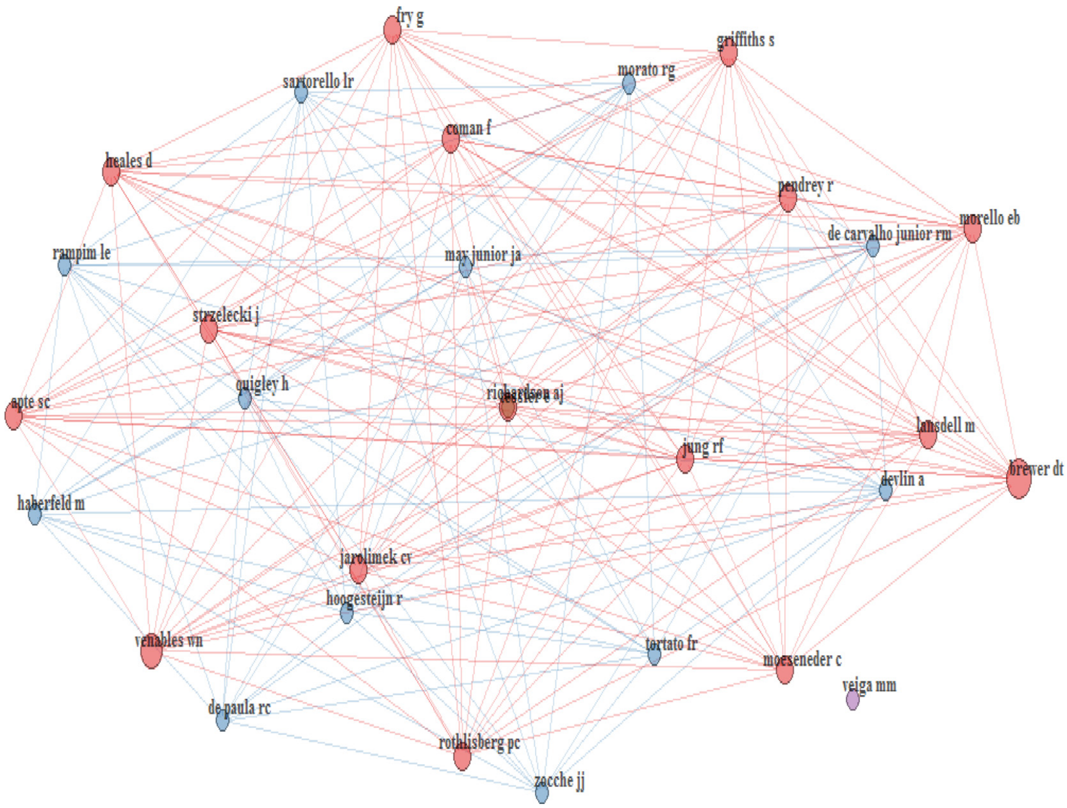

Fig. 1. Authors coupling for the top twenty on GMIs research.

Table 1
Most relevant keywords.

SN.	Authors Keywords (DE)	Art	Keywords-Plus (ID)	Articles
1	Mercury	14	Sediments	14
2	Mining	12	Contamination	12
3	Gold Mining	9	Fish	11
4	Heavy Metals	9	Heavy-Metals	10
5	Cyanide	5	Pollution	9
6	Artisanal Mining	4	Amazon	7
7	Gold Mine	4	Acid-Mine Drainage	6
8	Arsenic	3	Mercury	6
9	Bioavailability	3	Speciation	6
10	Cyanidation	3	Basin	5
11	Environment	3	Brazilian Amazon	5
12	Ghana	3	Exposure	5
13	Gold	3	Methylmercury	5
14	Methylmercury	3	Mine	5
15	Sediment	3	River	5
16	Acid Mine Drainage	2	China	4
17	Artisanal Gold Mining	2	Ghana	4
18	ASGM	2	Lake	4
19	Biomagnification	2	Region	4
20	Brazil	2	Soils	4

The 20-element cluster in Fig. 1 explains the authors coupling on GMIs-related research on the environment. Other indicators of frequently represented concepts and frameworks related to GMIs include country collaboration (Fig. 2), co-occurrence of terms and keywords (Fig. 3). The information in Fig. 3 shows the co-occurrence network of the top 50 keywords, co-occurrence network visualisation and association strength of global GMIs, and impact associated with various environmental indicators during the survey period, while Fig. 5 shows the university collaboration networks. These concept-related frameworks on co-occurrence visualisation of mining effects on environmental health or terms include acid mine drainage, contamination, environmental impact, exposure, fish, heavy metals, lake, methyl-mercury, mine tailings, pollution, sediments and water. Thus, the visualisation of the occurrence of keywords has revealed the potential or association strength between the two terms "GMIs" and "environmental components". In general, the smaller the distance between the two terms, the greater the relatedness of the terms, as measured by co-occurrences. More so, colors show the probabilistic impact index between GMIs and other environmental components such as water pollution, air pollution, heavy metals, contamination, i.e. there exists a significant relationship between GMIs and different

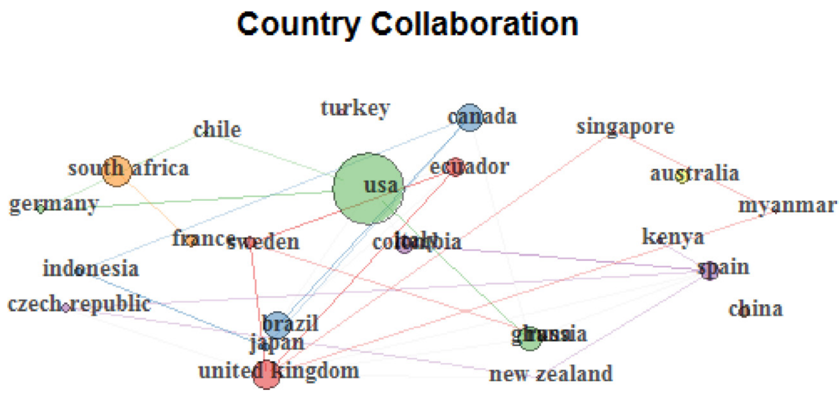

Fig. 2. Country collaboration for the top 25 networks on GMIs research.

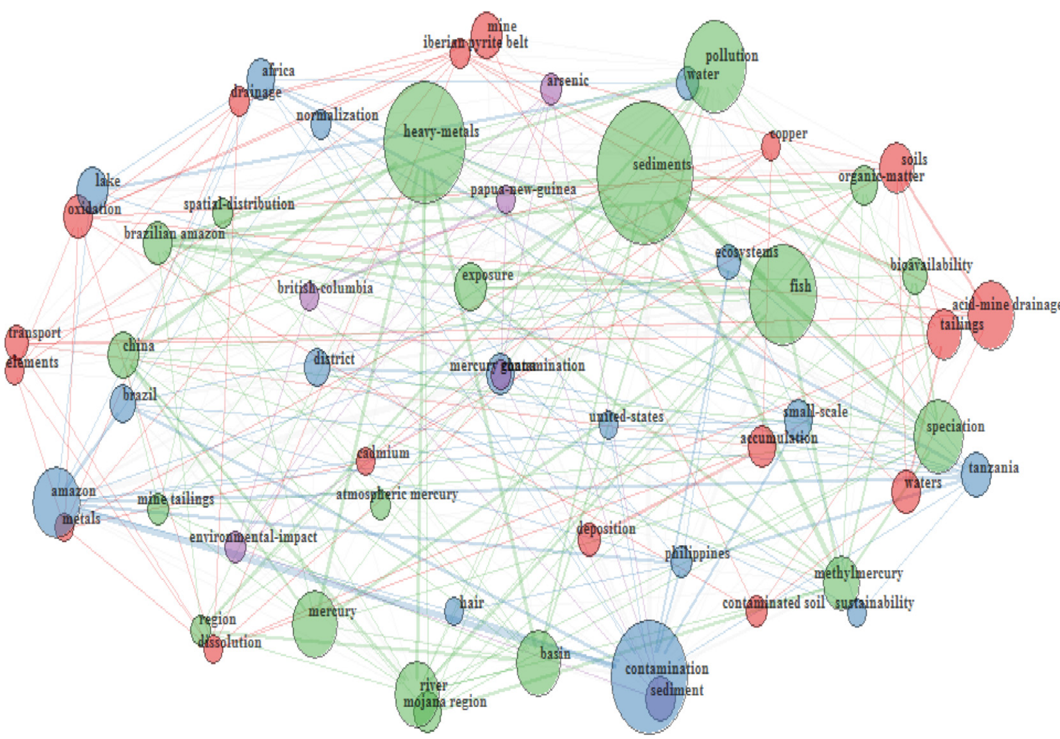

Fig. 3. Fifty keywords co-occurrence network visualisation and association strength of global GMIs studies.

aspects of the environment as mentioned earlier which might have contributed immensely to the recent environmental injustice globally (Li and Zhao, 2015).

Fig. 4 shows the summarised word occurrence frequency for the top 100 most used title keywords on GMIs research. Wordcloud was used on the titles of published papers of the most commonly used terms in GMIs studies during the period of investigation. This demonstrated the predominant word or term in GMIs research. It is easy to distinguish within the wordcloud on GMIs research and figure out different areas of associations and identify the most dominant terms used during the period. For instance, gold mining, environmental issues, impact, chemical distribution, human exposure, agricultural challenges, sediments, artisanal mining, pollution, ecosystem, waste, concentration, cyanide were identified as the most common or dominant terms in GMIs research.

Multiple affiliations of authors have contributed immensely to the country and university collaboration networks (Figs. 2 and 5). Our results revealed that most studies on GMIs between 1990 and 2018 were from universities based in developed countries, with a few from transition nations such as South Africa which produces about 14% of the articles published on GMIs during the study period. The University of Nevada (USA) and the University of Florida (USA) had the highest collaboration on GMIs studies followed by University Cordoba (Spain) and University of Witwatersrand (South Africa). Conversely, the low contributions were from developing countries including countries from Africa which are characterised by a high frequency of self-funded or independent studies (Huang et al., 2016).

To verify the scholarly activities in terms of research on the impacts of gold mining activities on the immediate environment, this study analysed gold production statistics per country to assess the number of research published on GMIs versus gold production rate in each country. Figs. 6 and 7 show the gold production per year (2012–2016, based on the available gold production records) for the 20 most productive countries and their research articles on GMIs during the study period. The gold production per year (2016) for the top research published in 20 countries on GMIs and their rank on gold production (kg) (2015 and 2016) were analysed.

Fig. 4. Wordcloud or word occurrence frequency of top 100 most used title keywords on GMIs.

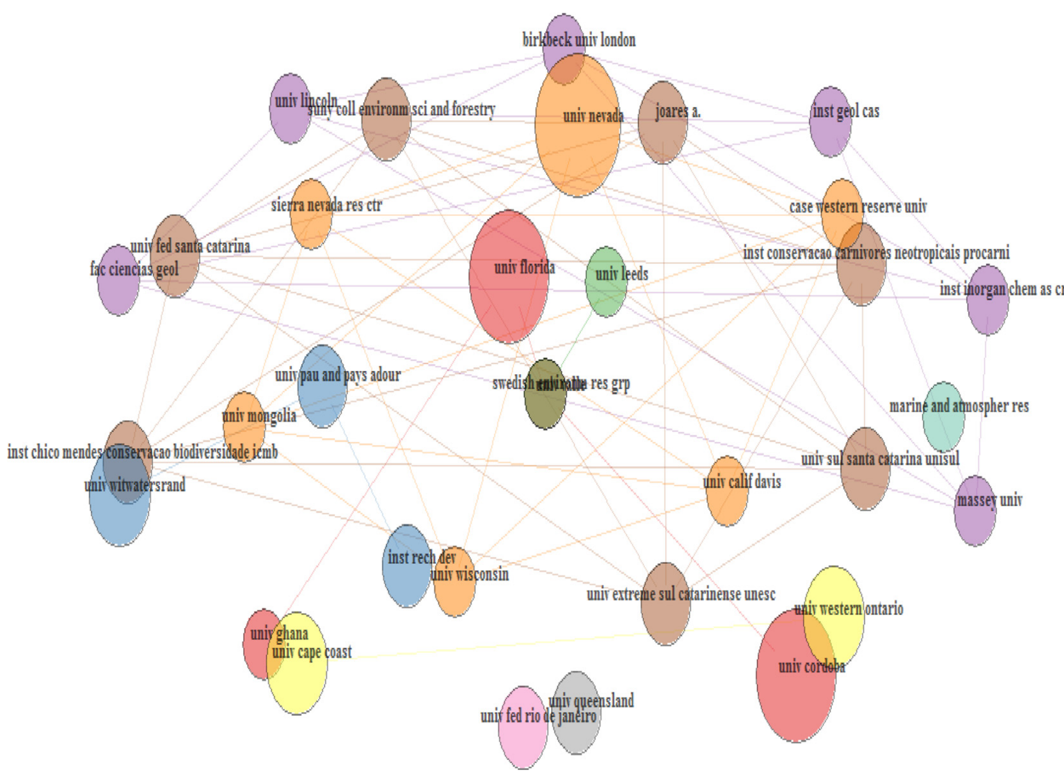

Fig. 5. Top 30 universities collaboration networks on GMIs research.

The results show that China had the highest gold production with about 453,500, 451,799, 450,053 and 428,160 kg in 2016, 2014, 2015 and 2013 respectively, with five (5.75%) research articles published on GMIs during the survey period, while Australia ranked second in gold production between 2012 and 2016 with annual production figures of 282,421, 279,190, 274,047 and 267,0862 in 2016, 2015, 2014 and 2013 respectively, with six (7%) published research articles on GMIs during the same period. USA had the highest research published articles on GMIs (28, 32%), and annual gold production figures of about 234,623, 229,703, 222,211 and 213,808 in 2012, 2013, 2016 and 2015 respectively, followed by South Africa with a total of 12 (13%) published articles, and gold production figures of about 160,016, 155,286, 151,622 and 144,504 in 2013, 2012, 2014 and 2015 respectively.

Even though China had the highest gold production figures, their research outputs on GMIs related studies were not commensurate with the gold production rates as shown in the study. With the increase in gold mining operations, there are potential implications of this operation on environmental and human health in the

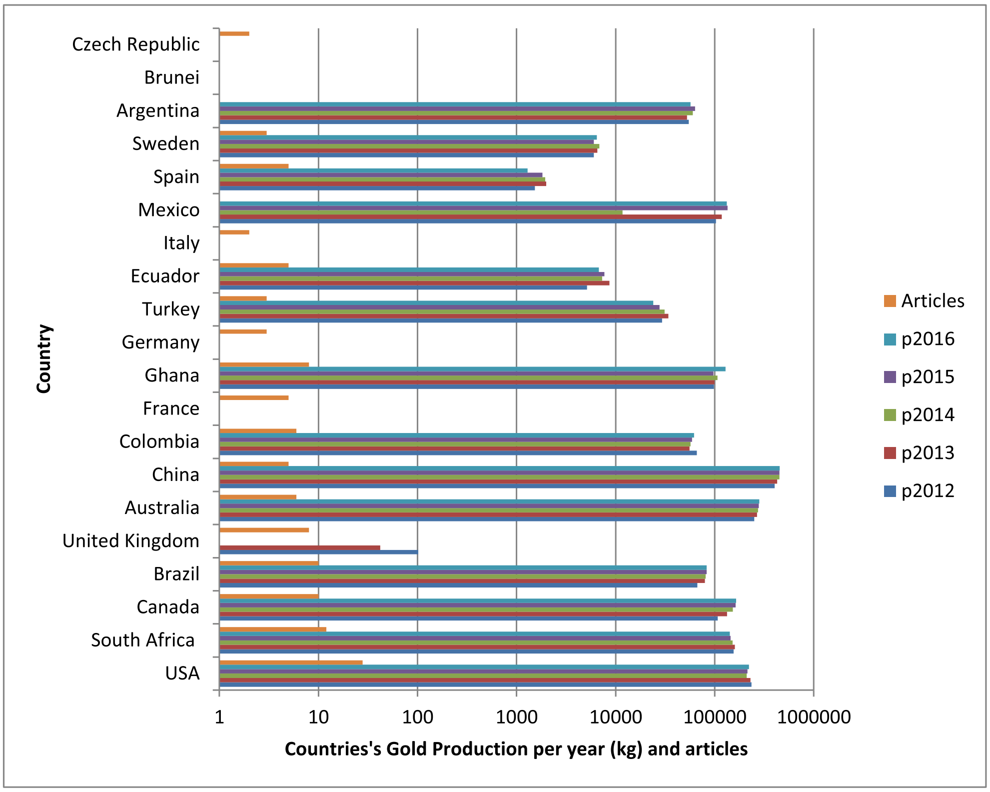

Fig. 6. Gold production per year (2012–2016) for the twenty most productive countries and their research articles on GMIs during the study period. Gold production per year (kg) displayed axis using a log 10 base scale.

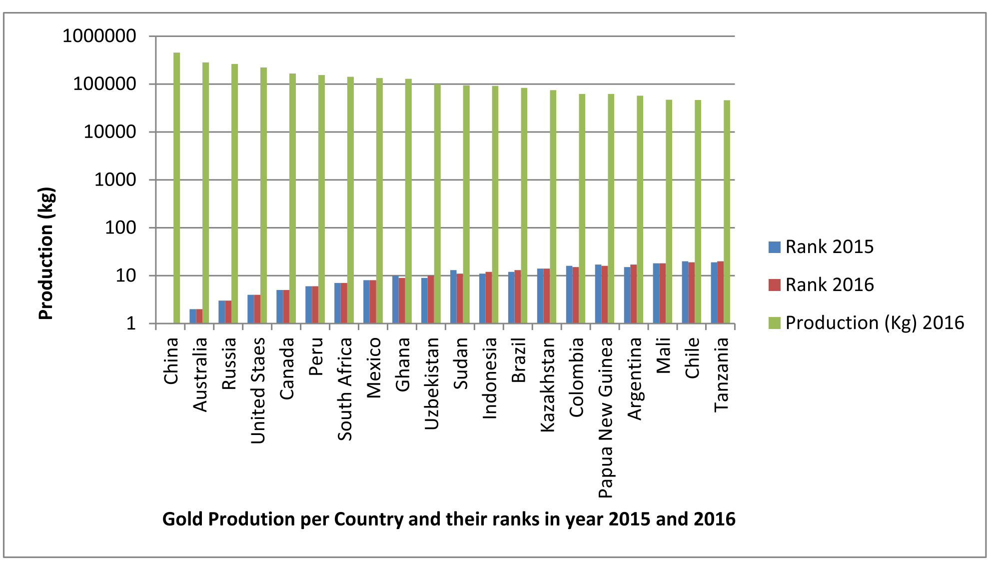

Fig. 7. Gold production per year (2016) for the top twenty countries and their rank on gold production (kg) (2015 and 2016). Gold production (kg) displayed axis using a log 10 base scale.

region (Kim et al., 2018). Per contra, USA and South Africa had the highest research articles published on GMIs despite their ranking in gold production; the concern about the adverse effects of gold mining activities through research is worthy of emulation by the transition and developing nations where mining and other human activities have impacted significantly on the environment (Darkoh, 2018).

5. Discussion

This study carried out a global assessment of research that has been done on gold mining and its impacts on the environment between 1990 and 2018. Specifically, the patterns and evolution of gold mining-related studies for the period were analysed, and the proximity of gold mining operation effects on the immediate environment was also evaluated. This study identified the potential implications of mining operations on various aspects of the environment during the survey period. Of note is that mining operation has been linked to some environmental indications over the years, especially where environmental regulations might have been compromised (Papworth et al., 2017).

Recently, there has been an increase in environmental related research involving some environmental components such as soil, water, air, biodiversity and aquatic life. The results from this study highlighted the top country collaborations and institutions. USA and United Kingdom ranked first and second in terms of collaboration and productivity on GMIs related studies during the period of study. This include international collaborative research on GMIs which is very important to mitigate the impacts associated with mining and other human activities. The findings of studies in environmental related fields, particularly in the case of GMIs are potential resource for the rest of the world as indicated by researchers in the USA and other developed nations.

The relationships between mining activities and the environment are particularly complex and not yet fully explored especially in the developing countries where only a few studies have been carried out on GMIs. This complexity maybe due partly to the level of research and lack of adequate analytical capabilities as well as the foolproof diagnostic ability for environmentally related health conditions in some parts of the world. For example, Kenya, Nigeria and other African nations that are facing environmentally impaired situations due to mineral explorations (Gafur et al., 2018; Odumo et al., 2018). Thus, concerted efforts are needed to increase environmental related mining impacts research not just focused on gold mining alone but other commodities in developing countries.

6. Conclusion

This study aimed to facilitate research on GMIs on the immediate environment with potential implication on human health, utilising scientometric analysis of related publications from 1990 to 2018. The assessment and approaches described in this study helped to increase the understanding of problems associated with the GMIs globally. In addition, the results from this study enabled consensus building and aided the effective understanding GMIs have on environmental components. This scientific findings will help stakeholders including those in decision-making positions implement environmental protection regulations and supports for researchers in the field. This study also revealed that most studies on GMIs were from developed nations with only a few from transition countries such as South Africa. More research focused on mining related impacts are needed in developing countries where mining operations are taking place. Although this field has not yet received substantial attention from researchers and regulatory bodies in most developing countries, it has the potential to evolve and produce highly influential research that will help mitigate the environmental impacts associated with mining activities. This study undoubtedly has distinct strengths. Based on findings from this study, different research database should be incorporated for the identification of other potential research trends and evolution in GMIs related research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jksus.2020.03.033.

References

Aleixandre-Benavent, R., Aleixandre-Tudó, J.L., Castelló-Cogollos, L., Aleixandre, J.L., 2017. Trends in scientific research on climate change in agriculture and forestry subject areas (2005–2014). J. Cleaner Prod. 147, 406–418.

Aria, M., Cuccurullo, C., 2017. bibliometrix: an R-tool for comprehensive science mapping analysis. J. Inform. 11 (4), 959–975.

Darkoh, M.B., 2018. Human Impact on Environment and Sustainable Development in Africa. Routledge.

Ekundayo, T.C., Okoh, A.I., 2018. A global bibliometric analysis of Plesiomonas-related research (1990–2017). PLoS ONE 13 (11).

Fashola, M., Ngole-Jeme, V., Babalola, O., 2016. Heavy metal pollution from gold mines: environmental effects and bacterial strategies for resistance. Int. J. Environ. Res. Public Health 13 (11), 1047.

Fedderke, J.W., Goldschmidt, M., 2015. Does massive funding support of researchers work?: Evaluating the impact of the South African research chair funding initiative. Res. Policy 44 (2), 467–482.

Gafur, N., Sakakibara, M., Sano, S., Sera, K., 2018. A case study of heavy metal pollution in water of bone river by artisanal small-scale gold mine activities in Eastern Part of Gorontalo, Indonesia. Water 10 (11), 1507.

Guerry, A.D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G.C., Griffin, R., Feldman, M.W., 2015. Natural capital and ecosystem services informing decisions: from promise to practice. Proc. Natl. Acad. Sci. 112 (24), 7348–7355.

Huang, J., Tang, J., Qu, Y., Zhang, L., Zhou, Y., Bao, S., Mu, D., 2016. Mapping the knowledge structure of neonatal hypoxic-ischemic encephalopathy over the past decade: a co-word analysis based on keywords. J. Child Neurol. 31 (6), 797–803.

Kim, Y., Tanaka, K., Ge, C., 2018. Estimating the provincial environmental Kuznets curve in China: a geographically weighted regression approach. Stoch. Env. Res. Risk Assess. 32 (7), 2147–2163.

Lee, J.C., Ilyas, S., 2018. Artisanal gold mining and amalgamation. In: Gold Metallurgy and the Environment. CRC Press, pp. 29–50.

Li, W., Zhao, Y., 2015. Bibliometric analysis of global environmental assessment research in a 20-year period. Environ. Impact Assess. Rev. 50, 158–166.

Nicholls, P.T., 1989. Bibliometric modeling processes and the empirical validity of Lotka's law. J. Am. Soc. Inf. Sci. 40 (6), 379–385.

Odumo, B.O., Nanos, N., Carbonell, G., Torrijos, M., Patel, J.P., Rodríguez Martín, J.A., 2018. Artisanal gold-mining in a rural environment: land degradation in Kenya. Land Degrad. Dev. 29 (10), 3285–3293.

Ogola, J.S., Mitullah, W.V., Omulo, M.A., 2002. Impact of gold mining on the environment and human health: a case study in the Migori gold belt, Kenya. Environ. Geochem. Health 24 (2), 141–157.

Orimoloye, I.R., Kalumba, A. M., Mazinyo, S.P., Nel, W., 2018. Geospatial analysis of wetland dynamics: wetland depletion and biodiversity conservation of Isimangaliso Wetland, South Africa. Journal of King Saud University-Science.

Orimoloye, I.R., Mazinyo, S.P., Kalumba, A.M., Nel, W., Adigun, A.I., Ololade, O.O., 2019. Wetland shift monitoring using remote sensing and GIS techniques: landscape dynamics and its implications on Isimangaliso Wetland Park, South Africa. Earth Sci. Inform. 12 (4), 553–563.

Palacios-Torres, Y., Jesus, D., Olivero-Verbel, J., 2020. Trace elements in sediments and fish from Atrato River: an ecosystem with legal rights impacted by gold mining at the Colombian Pacific. Environ. Pollut. 256, 113290.

Papworth, S., Rao, M., Oo, M.M., Latt, K.T., Tizard, R., Pienkowski, T., Carrasco, L.R., 2017. The impact of gold mining and agricultural concessions on the tree cover and local communities in northern Myanmar. Sci. Rep. 7, 46594.

Spiegel, S.J., Agrawal, S., Mikha, D., Vitamerry, K., Le Billon, P., Veiga, M., Paul, B., 2018. Phasing Out Mercury? Ecological economics and indonesia's small-scale gold mining sector. Ecol. Econ. 144, 1–11.

Tegegne, Y.T., Lindner, M., Fobissie, K., Kanninen, M., 2016. Evolution of drivers of deforestation and forest degradation in the Congo Basin forests: exploring possible policy options to address forest loss. Land Use Policy 51, 312–324.