A Scientometrics View on Sustainable Development in Surface Mining: Everything from the Beginning

Mahdi Pouresmaieli[1], Mohammad Ataei[2*], Ali Nouri Qarahasanlou[2]

[1] Ph.D. Student, Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology, Shahrood, Iran

[1] Professor, Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology, Shahrood, Iran

[2]Assistant professor, Faculty of Technical & Engineering, Imam Khomeini International University, Qazvin, Iran

Abstract

In summary, the study on sustainable development in the late 20th century aimed to balance economic, social, and environmental factors in open-pit mining. The study found that while mining has negative ecological impacts, it also has positive economic and social benefits. The study analyzed 77 articles and found a growing trend in scientific interest in sustainable development research from 1985 to 2022. This suggests that there has been a growing trend in using qualitative research methods in studies related to sustainable development in the mining industry in the past ten years. This is likely due to a shift in focus toward finding ways to improve the positive impacts and mitigate the negative impacts of this development in light of technology advancements and changes in environmental and social regulations. This highlights the importance of using a comprehensive approach that considers all aspects of sustainable development in studying small-scale mining. Given the significance of small-scale mining to the economies of many mining communities, it is crucial to develop clear regulations and guidelines that align with the principles of sustainable development. This will help ensure that the industry operates responsibly and sustainably. This statement emphasizes the importance of updating research methods to reflect the latest technological advancements and the interdisciplinary nature of sustainable development. As technology and other fields of study continue to advance and intersect with the issue of sustainable development in the mining industry, it is essential to incorporate these new advancements and perspectives into future studies. This will help ensure that research in this area remains relevant and comprehensive.

Keywords: Sustainable development, social, economic, environmental, analysis

1- Introduction

The concept of sustainable development and mine planning and design, especially for open-pit mining, are presented as a comprehensive mining plan. Due to population growth and increased demand for and consumption of minerals and metals, mineral production has been boosted, and mines are located near urban and rural areas. Based on the definition of sustainable development, determining ultimate pit limits irrespective of the sustainable development indicators (i.e., environmental, economic, and social factors (Figure 1)) is not an effective scientific way of production planning and design (Pouresmaieli and Osanloo 2019b).

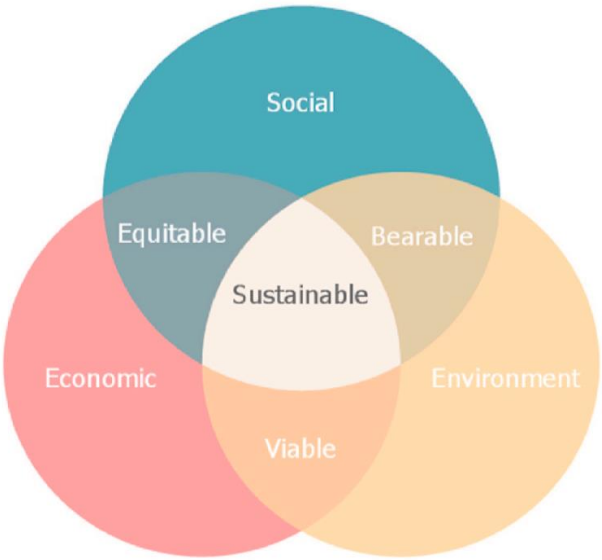

Figure 1. Indicators of sustainable development (Pouresmaieli et al. 2022; Pouresmaieli, Ataei, and Taran 2022)

Nowadays, the most significant goal of mine design is to maximize the current net worth by considering issues related to sustainable development (Pouresmaieli and Osanloo 2019a). The major objective of short-term and medium-term plans is to achieve the predetermined goals in the long-term plans as much as possible. Strategic and long-term mine design is currently carried out for two primary purposes (Ekrami et al. 2022):

- Paying attention to the payback period: Attempting to shorten this period (between 6 and 8 years).
- Designing following sustainable development: Trying to align mine design with the Sustainable Development Goals (SDGs).

At the Rio Conference in 1992, this critical issue (sustainable development) was defined as convergence between the three dimensions of economy, society, and the environment. A set of SDGs was developed in 2015. They obliged countries around the world to comply with these SDGs. The Sustainable Development Goals (SDGs) or Global Goals are a set of 17 interconnected

global goals designed to create a shared plan for peace and prosperity for people and the planet, now and in the future (Pouresmaieli et al. 2022; Pouresmaieli, Ataei, and Taran 2022). The Sustainable Development Goals were set by the United Nations General Assembly (UN-GA) in 2015 and are set to be achieved by 2030. In the subsequent years, King introduced sustainable mining and drew attention to rehabilitation costs (Drebenstedt 2014).

By reviewing the previous (especially the latest) articles, the current study aims to analyze all the methods used to evaluate sustainable development in open mines and compare the benefits, drawbacks, and applications of the most frequently used ones. The current undesirable mining conditions in the world, the decreased grade of geological resources and the remaining extractable reserves, and an increase in mining depth and tailings volumes confirm a substantial boost in damaged lands due to mining activities. Based on studies in Canada, the excavation of 0.5 million tons of ore through open-pit methods has adversely affected 100 hectares of land, which indicates the importance of attending to sustainable development in this industry (Laurence 2011). Thus, constructing and developing new mines should be accomplished by optimally using mineral resources and lessening negative environmental impacts (Ebrahimabadi et al. 2018).

In 1987, the World Commission on Environment and Development, the Brundtland Commission (WCED), defined sustainable development in a report entitled "Our Common Future." Based on this definition, sustainable development is "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Environment, Development, and Brundtland 1987). The concept of sustainable development is often considered an indicator of the development of modern society. The term was first used in 1713 by Hans Karl von Carlowitz, a Saxon mining inspector. At that time, the demand for wood was on the rise since it was largely used to manufacture construction equipment and maintain underground mines. As a result, deforestation largely increased in the world. Carlowitz proposed strategies to decrease (wood) consumption, elevate afforestation and enhance sustainability (Drebenstedt 2014; King 1998). Generally, the approaches to sustainable development in mines are implemented at the beginning of a mine's life cycle, during extraction operations, or mine closure (Amirshenava and Osanloo 2018).

According to the data obtained from the Scopus website, from the beginning to August 19, 2022, 998 articles were published on sustainable development (Figure 2). Some points will be mentioned about this data in the discussion section. In this review article, the articles that have been published on the main topic of sustainable development in open pit mines will be examined. Based on the historical trend from 1990 to 2022, 250 articles undertaken on sustainable development in mining are reviewed and compared in terms of their methods, benefits, weaknesses, and common features. Among these 250 articles, 77 articles were published. Among these 250 articles, 77 articles that were valid in the journals of interest to the authors were selected for study in this article.

Figure 2. Articles published on the Scopus site on the topic of sustainable development in mines (Date assessed: August 19, 2022)

This article aims to improve understanding and promote sustainability in the mining industry by analyzing existing research on sustainable development. The article is structured into five main sections:

1. Introduction
2. Examination of sustainable development concepts and their application in mining
3. Methodology for selecting and summarizing articles
4. Results, findings, and analysis of studied articles on sustainable development in mining
5. Conclusions.

This article is important for those interested in promoting sustainability in the mining industry and understanding the progress and challenges in this field. Compared to previous works, one of the unique aspects of this article is its focus on studying innovation and technology through an analytical framework in the context of sustainable development. The results of this study can help identify gaps in previous research and provide a roadmap for future research and sustainable development efforts in the mining industry based on trends and developments from the beginning to 2022.

2- The necessity of sustainable mining

Sustainable development is not realized just by addressing environmental issues. In addition to eliminating environmental complications, sustainable development seeks to provide a better future for all the inhabitants of the planet Earth. Therefore, sustainable development involves converging the three pillars of economic viability, social equity, and environmental protection (Amiri et al. 2017).

In 2011, studying 1,000 mines that were inactive from 1980 to 2011, Laurence introduced mine closure as an unsustainable issue. He underscored that any efforts to sustain mining operations should be consistent with the environment, economy, society, and mine productivity. Laurence presented five criteria for sustainable development; in other words, he added the criteria of safety and resource efficiency to the three abovementioned pillars. The reason for the inclusion of safety

and resource efficiency, as he argues, is that the government owns some sectors of mines in many parts of the world (Laurence 2011).

In general sustainability of mines can promote job opportunities, GDP, local people's employment, and residents' satisfaction in mining areas, develop villages around mining sites, increase cultural and language transfer (in case foreign companies are involved), and booms business in the community.

Mining activities are closely related to sustainable development as they have constructive and destructive effects on the three indicators of society, the environment, and the economy. Despite many efforts at international, national, and local scales since 1990, sustainable development has not been able to find its place in the mining industry. Land degradation, land subsidence, soil pollution, air pollution, the depletion of natural resources, and a growing number of endangered plant and animal species are the ramifications of neglecting sustainable development goals. These negative impacts bring about uncontrollable physical, chemical, and biological alterations in the ecosystem of this planet in the future (Hartman et al. 1992). Table 1 reports the destructive and constructive effects of mining, and Table 2 presents the ecological effects of mining on water resources, air quality, wildlife, soil quality, and climate change.

Table 1: Positive and negative effects of mining (Pouresmaieli and Osanloo 2019b)

Positive effects of mining	Negative effects of mining
1. Advancement of technology 2. Job creation and employment opportunities 3. Production of essential raw materials and achievement of self-sufficiency 4. Production of wealth through taxes, etc.	1. Pollution and damage to the environment 2. Climate change 3. Social turmoil 4. Visual pollution (changing the land view)

Table 2: Ecological impacts of mining (Pouresmaieli and Osanloo 2019b)

Water resources	Acid mine drainage Soil erosion and infiltration of mineral wastes into surface waters Waste dump, waste rock, leaching
Air quality	Floating resources (particles, carbon monoxide, and organic compounds) Fixed resources (mercury, arsenic, sulfur dioxide, and other metals) Volatile gases, partial emission of mercury Noise and vibration
Wildlife	Loss of animal habitat Biodegradation
Soil quality	Impacts on activities related to soil, such as agriculture
Climate change	Emission of carbon dioxide and toxic gases due to an explosion

3- Contents of Literature Review

Numerous studies have been conducted on sustainable development since 1985. Among them, 77 articles are reviewed in the current study. To select these 77 articles, First, about 250 articles were studied. Among these 250 articles, 156 were classified with SJR Q1 or Q2. Then, the interest of researchers in publishing articles in the field of sustainable development in mining in each journal was measured. The articles in journals with an interest rate above 2.5% were reviewed in this article (Table 3). According to the above limitations, the number of reviewed articles was 77.

Table 3: Interest of researchers to publish articles on sustainable development in mining in different journals

<table>
<tr><th>Journal name</th><th>SJR</th><th>The interest of researchers to publish articles in the field of sustainable development in mining (in percent)</th></tr>
<tr><td>Journal of cleaner production</td><td>Q1</td><td>13.3%</td></tr>
<tr><td>Resources Policy</td><td>Q1</td><td>5.4%</td></tr>
<tr><td>Science of the total environment</td><td>Q1</td><td>4.1%</td></tr>
<tr><td>Mine water and environment</td><td>Q2</td><td>3.5%</td></tr>
<tr><td>Environmental geochemistry and health</td><td rowspan="4">Q1</td><td rowspan="6">The interest of researchers to publish in each journal
≥3%
Totally
≥18%</td></tr>
<tr><td>Environmental pollution</td></tr>
<tr><td>Environmental impact assessment review</td></tr>
<tr><td>Environmental science & policy</td></tr>
<tr><td>Environmental geology</td><td rowspan="2">Q2</td></tr>
<tr><td>Impact assessment and project appraisal</td></tr>
<tr><td>Minerals engineering</td><td rowspan="2">Q1</td><td rowspan="5">The interest of researchers to publish in each journal
≥2.5%
Totally
≥12.5%</td></tr>
<tr><td>Journal of environmental management</td></tr>
<tr><td>Environmental monitoring and assessment</td><td rowspan="3">Q2</td></tr>
<tr><td>Applied geochemistry</td></tr>
<tr><td>Environmental earth science</td></tr>
<tr><td>Journal of environmental quality</td><td rowspan="6">Q1</td><td rowspan="8">The interest of researchers to publish in each journal
≥1.5%
Totally
≥13.5%</td></tr>
<tr><td>Chemosphere</td></tr>
<tr><td>Ecological indicators</td></tr>
<tr><td>Environment development and sustainability</td></tr>
<tr><td>Geoderma</td></tr>
<tr><td>Extractive industries and society</td></tr>
<tr><td>Journal of geochemical exploration</td><td rowspan="2">Q2</td></tr>
<tr><td>Journal of environmental radioactivity</td></tr>
</table>

Bulletin of environmental contamination and toxicology		
Other journals		≤29%

Due to the large amount of content in the studied articles, the reviewed articles are summarized in Table 4 (Only articles from 2017 to 2022 are written in text form in this article). According to the studied articles, it was found that most of the articles in the early period (from 1985 to 2000) were focused on the quantitative method. The second period (from 2000 to 2010) showed that researchers have also used semi-quantitative methods due to increasing awareness of the science of sustainable development in mining. Studies in this period have been mainly focused on quantitative and semi-quantitative methods. In the third period (from 2010 to 2022), due to the advancement of technology and the increase of findings in the field of sustainable development in mining, the articles published in this period mostly included qualitative and quantitative methods. All the reviewed articles in this section are summarized in Table 4.

In summary, the study by Ali et al. found that the river sediments in the Sydney Basin, Australia, were contaminated by coal mining operations, particularly with arsenic, nickel, and zinc. The soil near coal mining sites was also heavily polluted with manganese, zinc, cobalt, nickel, and barium. The study highlights the need for proper permitting for tailings disposal to prevent further pollution. (Ali et al. 2018). Bui et al. used a semi-quantitative framework based on the fuzzy analytic hierarchy process (AHP) method to assess the influence of various economic, environmental, and social indicators on coal mining operations. They found that the most influential factors were energy consumption, capital needed for mine closure and rehabilitation, and mining facilities. (Bui et al. 2017). Dialga proposed a semi-quantitative framework for assessing sustainable development in countries with abundant mineral resources. The framework comprises five indicators: economic, social, environmental, governmental, political, and impacting institutional factors, each with its sub-indicators. The results of applying the framework in Burkina Faso and Nigeria showed a strong connection between the economy and sustainable development indicators. (Dialga 2018).

Cheng et al. conducted a study in 2018 to assess soil contamination by heavy metals from lead and zinc mines in Yunnan, China. They collected 40 samples and found that arsenic, cadmium, lead, and zinc levels exceeded the maximum permitted levels, indicating negative environmental impacts from mining activities. These heavy metals' main sources were mining operations, the dispersion of coal particles, seasonal weather, dust, greenhouse gas emissions, and tailings dams. (Cheng et al. 2018). Farahani and Bayazidi conducted a qualitative study in 2018 to examine sand mines' social, economic, and environmental impacts on local communities. They administered questionnaires to 254 residents from 18 villages and found that the level of welfare and economy had improved, but the environment had been negatively impacted (Farahani and Bayazidi 2018). Gupta et al. proposed an optimal model combining hierarchical and multi-criteria analysis for sustainable transportation in the mining industry. They aimed to promote sustainable transportation to preserve the environment, increase delivery speed, reduce shipping costs, and enhance safety. The model can reduce dependence on diesel fuels, lower greenhouse gas emissions, and provide the optimal number of vehicles for moving minerals, contributing to improved sustainability in the mining industry (Gupta et al. 2018). Hadzi et al. found that heavy metal pollution of water in the gold mines in Ghana significantly impacted human health. They concluded that the high levels of arsenic in the areas around the mines increased the risk of cancer,

and the presence of heavy metals in surface water posed a threat to human health. Meanwhile, Hresc et al. explored the relationship between the economic effects of mining and social health using document analysis. They found that the two were closely related, but more research was needed. (Hadzi, Essumang, and Ayoko 2018). In 2018, Kolotzek et al. proposed a model for assessing the risks of raw material supply, environmental impacts, and social consequences, which found that by substituting raw materials or using special technologies and diversifying the supply of raw materials, the risks can be reduced. Rakotondrabe et al. studied the water quality around a gold mine in Cameroon and found that the water was no longer suitable for human consumption due to high levels of cadmium, lead, iron, cadmium, and chromium. Zvarivadza, in another study, concluded that handicrafts and small-scale mining were major concerns in sustainable development in small towns and developing countries and that the government should recognize these activities as a way to promote sustainable livelihoods.

In a series of studies conducted in 2018 and 2019, various researchers have explored the impacts of mining activities on sustainability. They investigated the impacts on human health, social health, the environment, the economy, and sustainable development. Results showed that the areas with high levels of heavy metals in water were contaminated, and the presence of heavy metals posed a threat to human health. The areas with rich resources were in good condition, while the areas with poor mineral resources were unsustainable and needed more support. The operations in sand, coal and iron mining were found to have the greatest impact on deforestation in India. The ecological approaches to mining in Finland showed a gap between regulations and actual practice in fulfilling social and environmental obligations by mining companies. A model for evaluating sustainability indicators revealed moderate levels of sustainability for two iron ore mines in Iran. Studies showed that sustainable development in the mining industry was positively related to reducing energy consumption, increasing the use of renewable resources, and achieving cleaner production. The Paris Agreement, signed in 2015, aimed to reduce and prevent global warming and greenhouse gas emissions until 2030. The study on implementing sustainable development policies in 100 mining projects showed that properly implementing these policies could reduce mineral waste and increase economic, social, and environmental benefits. The study on the role of mining activities in sustainable development indicators showed that mining directly impacted employment, poverty reduction, and hunger but also posed challenges in gender equality and climate activities.

The role of sustainable development in gold mines has received much attention in the last decade. Sustainable development in the mining sector has been a focus of several international programs such as the ICMM and UNDP. The United Nations Sustainable Development Goals (SDGs) have been widely accepted and politically legitimized since their announcement in 2015. Andrews and Essah proposed a new framework to help increase the contribution of sustainable development in the gold mining sector and found that it had several advantages, including improved assessment of project impacts, increased government accountability, and a criterion for negotiating mining agreements based on sustainable development principles. Hirons emphasized the importance of modifying large-scale mining policies, formalizing small-scale mining, and expanding knowledge to improve sustainable development prospects in the sector. Endl et al. found that mining innovations had implications for each sustainable development goal, and more research was needed on their overall impact. European Union countries, including Germany, Finland, Britain, Portugal, and Greece, have altered their mining policies to follow the SDGs by emphasizing waste and climate management.

Small-scale mining has significant environmental impacts in Tanzania, Guyana, Sierra Leone, and China, including deforestation, water and soil pollution, noise and dust, and health problems. The Tanzanian government has modified regulations in the past five years to align with sustainable development goals, but enforcement is limited, and miners have low environmental awareness. Small-scale mining has become a significant source of economic growth and poverty reduction in Guyana but has also caused environmental degradation. In Sierra Leone, the decentralization of mining permits has led to the growth of small-scale mining, but the resulting informal and problematic changes have hindered sustainable development. The Life Cycle Assessment of coal mining in China revealed environmental pollution, freshwater contamination, and health problems, with steel and electricity consumption and mining ventilation among the factors affecting the environment. Basic measures have been proposed to reduce the destructive effects of mining on the environment and increase production efficiency. Biosensors and nano-materials have been introduced for soil and water remediation.

Table 4: Summary of reviewed articles

No	Year	First Author	Main Subject	Conclusion	Method	Refrence
1	1985	Amaral	The effects of Brazilian uranium mining on the environment and soil	The presence of uranium in tomatoes, carrots, grapes, onions, fodder, and milk	Q	(Amaral, Azevedo, and Mendonca 1985)
2	1994	Spurgeon	Assessment of the environmental effects of metal mines	Accumulation of polluting elements in the area	Q	(Spurgeon, Hopkin, and Jones 1994)
3	1995	Castilla	Environmental effects of mineral waste disposal in northern Chile	The release of acid from copper tailings makes the soil resistant and the growth of some plant species, algae, and invertebrates.	Qu	(Castilla 1996)
4	1997	Gray	Investigating metal sediment pollution in a river downstream of Avoca mines in southeast Ireland	Possible methods to check, prevent and treat AMD	Q	(Gray 1997)
5	1998		The effects of AMD produced by mining activity on the ecology		Q	(Herr and Gray 1997)
6	2008		Investigation of AMD in a river in Ireland, resulting from a two-element sulfur-copper mine		Q	(Gray and Delaney 2008)
7	2000	Javris	Investigating the environmental outlook due to mining activities	The latest techniques are still weaker than what is needed	Q	(Jarvis and Younger 2000)
8	2001	Slootweg	Evaluation of a framework for the integration of social and environmental indicators	A better understanding of the effects of human activities on the environment	Qu	(Slootweg, Vanclay, and Van Schooten 2001)
9	2001	Steinemann	Improving alternative ways to improve the effects of environmental indicators resulting from mining activities	Inappropriate alternatives can undermine the goals of evaluating environmental indicators.	Qu	(Steinemann 2001)
10	2002	Kim	Assessment of heavy metal contamination in Dakom gold-silver mine in South Korea	Regular contact with the soil by the local population can be a potential health hazard due to exposure to toxic elements such as arsenic.	Q	(Kim et al. 2002)
11	2005		Modeling and risk assessment of arsenic and other heavy metals in five abandoned metal mines	Cancer risk with exposure to cadmium, zinc, and arsenic	Q	(Kim et al. 2005)
12	2002	DeNicola	Investigating AMD on communities in water streams	The chemical environment resulting from AMD greatly impacts living organisms and vegetation.	Q	(DeNicola and Stapleton 2002)
13	2008	Monjezi	Folchi model for 4 mines, Choghart, Sarchesmeh, Golgohar and Mute	Sarcheshmeh mine has the most unsustainability, and Mute mine has the most sustainability.	S	(Monjezi et al. 2009)
14	2003	Aslebekian	Investigating the environmental effects of silver mining in Ireland	Tailings dams have caused soil pollution in the region with cadmium, lead, and zinc elements.	Q	(Aslibekian and Moles 2003)
15	2003	Azapagic	Designing a general framework for evaluating sustainable development indicators	Evaluation of 6 economic, ten socials, and ten environmental indicators.	Qu	(Azapagic 2004)

No	Year	First Author	Main Subject	Conclusion	Method	Refrence
16	2005	Doupé	Environmental risk assessment of constructed lakes from the mined pit in South Western Australia	Coal mining lakes can be used as recreational and tourism sites, wildlife protection, aquaculture, irrigation, drinking water, industrial water, and possibly aquariums.	S	(Doupé and Lymbery 2005)
17	2005	Khan	Assessment of heavy metal pollution in surface water around coal mines and industrial complex in India	cobalt, chromium, and mercury above water quality standards; Cobalt, chromium, and mercury can accumulate in soil and enter the food chain, leading to serious health risks, local ecosystems, and long-term sustainable threats.	Q	(Khan et al. 2005)
18	2006	Akabzaa	Investigating AMD produced from 3 mines in Ghana	Six samples have a high acid potential, and the rest of the samples have a very low amount of carbonate and sulfur	Q	(Akabzaa, Armah, and Baneong-Yakubo 2007)
19	2006	Akcil	Description of AMD and technical issues related to it	primary prevention of the acid production process; Secondary control, which includes prevention of AMD migration outside the tailings dam, combined control or collection of AMD.	Qu	(Akcil and Koldas 2006)
20	2006	Gibson	Evaluation of sustainable development indicators and problems in it	The essential requirements for the implementation of sustainable development should be given more attention	Qu	(Gibson 2006b)
21	2006	Gibson	Evaluation of sustainability in a nickel mine	Culture, government priorities, and other official powers significantly contribute to sustainability.	Qu	(Gibson 2006a)
22	2006	Kitula	Environmental and Socio-Economic Impacts of Gita Local Mining in Tanzania	If the government supports the local workforce, improves regulations, and reduces illegal mining, social, economic, and environmental improvements will result.	Q	(Kitula 2006)
23	2006	Kumah	The impact of gold mining on sustainable development	Gold mining has many drawbacks, but employment and currency exchange can bring many benefits, especially to people in developing countries.	S	(Kumah 2006)
24	2006	Roychoudhury	Distribution and mobility of metals in mine waters in gold and silver mines	The mobility of nickel is the highest, the mobility of zirconium is the lowest, and pollution near tailings dams is high.	Q	(Roychoudhury and Starke 2006)
25	2006	Sheoran	Investigating the mechanism of heavy metal removal, which includes physical, chemical, and biological processes	Producing free drinking water from contaminated water and creating social responsibility for the treatment of acidic mine water	Qu	(Sheoran and Sheoran 2006)
26	2007	Neves	Evaluation of underground water quality and problems related to pollution in an abandoned mine	Toxic metals such as aluminum, manganese, and uranium in the food chain may pose a serious health risk to residents.	Q	(Neves and Matias 2008)
27	2008	Hacking	A qualitative framework to illuminate sustainable development	Evaluation approaches can be substituted for each other and compared based on substance rather than meaning	Qu	(Hacking and Guthrie 2008)
28	2008	Mudd	Preliminary assessment of injection water used in mines for sustainable mining	The production of ore and the use of water used in the mine. In general, it is a persistent problem for mining	Q	(Mudd 2008)
29	2009	Jha-Thakur	Survey and assessment of environmental impacts in India	Design and follow-up in India according to international principles is the best way to follow up on the assessment of environmental indicators in India	S	(Jha-Thakur, Fischer, and Rajvanshi 2009)

No	Year	First Author	Main Subject	Conclusion	Method	Refrence
30	2009	Rodrı´guez	Investigating the distribution of heavy metals and the formation of chemicals in the soil around the lead and zinc mine	Improper drainage of tailings dams and wind transport of dust as the main effects of pollution dispersion	Q	(Rodríguez et al. 2009)
31	2010	Singh	Environmental geochemistry and water quality assessment	The concentration of some metals (lead, nickel, copper, and iron) is higher than standard levels.	Q	(Singh et al. 2010)
32	2012				Q	(Singh et al. 2012)
33	2012	Phillips	Investigating the numerical model for sustainability calculation	Human interests are subtracted from sustainable indicators, and if the relationship is positive, it is concluded that mining is in line with sustainable development.	Q	(Phillips 2012)
34	2011	Campos	Evaluation of the environmental effects of uranium mining	The amount of pollutants and AMD leaked in the region has increased, and the health of the waters in the region has been weakened.	Q	(Campos et al. 2011)
35	2012	Giurco	The prospect of mineral resources	The important role of mineral processing and recycling is neglected	Qu	(Giurco and Cooper 2012)
36	2011	Laurence	The sustainability of mines based on mine closure	44%, 34%, 11%, 6%, and 5% of the mines that were closed prematurely have weaknesses in economic, productivity, society, environment, and safety indicators, respectively.	S	(Laurence 2011)
37	2006		Presenting a model to predict the probability of premature closure of mines		S	(Laurence 2006)
38	2011	Moreno	Presenting a new approach to investigating the environmental impacts of mining	The impact of mining on the ecosystem was high	Q	(Moreno-Jiménez et al. 2011)
39	2012	Alvarenga	Risk assessment of Sono Demingos mines in Portugal using soil physicochemical characteristics	Tested soil toxicity confirms the mortality rate, infections caused by these elements, plant growth, and soil contamination of the area caused by these elements.	Q	(Alvarenga et al. 2012)
40	2012	Huertas	Investigation of pollution caused by coal mining in Colombia	Mining companies were obliged to move three villages around mines to areas away from pollution	Q	(Huertas et al. 2012)
41	2012	Prno	Governance and sustainability theories for conceptualizing social certification in the mining sector	More research is necessary to determine government measures	Qu	(Prno and Slocombe 2012)
42	2013	Fonseca	Description, comparison, and critique of five sustainability methods and frameworks	There are more productive ways to enhance sustainability reporting	Qu	(Fonseca, McAllister, and Fitzpatrick 2013)
43	2013	Edraki	Designing and replacing plants around tailings dams for better environmental, social, and economic results	The concentration of materials within tailings dams, dam reuse, waste disposal, recycling and reprocessing, and preventive management can help replace vegetation around tailings dams for better environmental, social, and economic outcomes.	Qu	(Edraki et al. 2014)
44	2014	Fonseca	A qualitative model of sustainable development based on previous studies	The geographical dispersion of mining facilities creates important problems in the field of calculation of sustainable development assessment level	Qu	(Fonseca, McAllister, and Fitzpatrick 2014)

No	Year	First Author	Main Subject	Conclusion	Method	Refrence
45	2014	Li	Soil pollution by heavy metals in Chinese mines	Carcinogenic and non-carcinogenic risks from soil contamination by heavy metals threaten the general public, especially children and those who live in the vicinity of highly contaminated mining areas.	Q	(Li et al. 2014)
46	2015	Pourret	The environmental effects of mining due to the distribution of metals	The distribution of heavy metals is the biggest risk from mining activities	Q	(Pourret et al. 2016)
47	2016	Wang	Investigating environmental effects in a mining area based on geological conditions	In areas where surface water interferes with faults, much more pollution	S	(Wang et al. 2017)
48	2016	Antoniadis	Risk assessment of toxic elements in edible plants and vegetables	The soil around the mine is contaminated up to a radius of 35 km	Q	(Antoniadis et al. 2017)
49	2016	Driussi	Minimizing the amount of environmental pollution from the mine in Australia	Environmental management systems, advanced pollution control technologies, environmental awareness training for employees, and the requirements of the company's stakeholders to increase responsiveness to environmental impacts have led to the depreciation and improvement of pollution in this area.	Qu	(Driussi and Jansz 2006)
50	2016	Morrison	Integrating mine closure planning in African and Australian jurisdictions with environmental impacts	Implementation capacity is challenging for integrated mine closure programs and environmental impact assessments.	Qu	(Morrison-Saunders et al. 2016)
51	2016	Suopajärvi	Investigating sustainability in mining communities based on available evidence and documentation	Fear and anxiety about the negative environmental effects and the ability to live in the northern regions caused by mining is the main problem in the northern communities.	Qu	(Suopajärvi et al. 2016)
52	2017	Ali	Assessment of river sediment quality using sediment quality indicators for the Sydney Basin of Australia, affected by coal mining	Arsenic, nickel, and zinc as the main pollutants in sediments	Q	(Ali et al. 2018)
53	2017	Bui	Designing a semi-quantitative framework using the fuzzy AHP method	Capital closing and reclamation in the economic index, energy consumption in the environmental index, and mining facilities in the social index have the most importance.	S	(Bui et al. 2017)
54	2017	Dialga	A new semi-quantitative framework for assessing sustainable development in mineral-rich countries	Each indicator is converted into a measurable indicator and then weighted and summed.	S	(Dialga 2018)
55	2018	Cheng	Assessment of soil pollution by heavy metals	The concentration of arsenic, cadmium, lead, and zinc is higher than the permissible limit and negatively affects the environment.	Q	(Cheng et al. 2018)
56	2018	Farahani	Evaluation of social and economic effects and environmental effects of sand mines	The welfare and economic level of the region in the area around the mine have grown significantly.	Qu	(Farahani and Bayazidi 2018)
57	2018	Gupta	The optimal model of hierarchical analysis and multipurpose data coverage analysis for sustainable transportation in the mining industry	Reducing dependence on diesel fuels for transportation leads to a reduction in greenhouse gas emissions.	S	(Gupta et al. 2018)

No	Year	First Author	Main Subject	Conclusion	Method	Refrence
58	2018	Hadzi	Environmental pollution assessment of heavy metals in waters around gold mines in Ghana	The level of arsenic in these areas is at such a level that it can cause an increase in cancer for people in that area.	Q	(Hadzi, Essumang, and Ayoko 2018)
59	2018	Kolotzek	A model for raw material supply risk assessment	Substitution for raw materials or special technologies and a variety of raw material preparation, the risk of raw material supply can be reduced in these ways.	S	(Kolotzek et al. 2018)
60	2018	Rakotondrabe	Minimizing the amount of environmental pollution for the AngloGold mine in Australia	The waters around this mine have an acidic PH, and the suspended solid particles in the water are high.	Q	(Rakotondrabe et al. 2018)
61	2018	Zvarivadza	Raising handicrafts and small-scale mining as a challenge in sustainable development.	Governments must recognize these activities as a way for a sustainable livelihood.	Qu	(Zvarivadza 2018)
62	2019	Cui	Evaluating the sustainability of China's mining areas and their effects using a hierarchical method	One of the reasons for the lack of stability in some areas is the lack of abundant resources, and for this reason, there is not enough support for those areas.	S	(Cui et al. 2019)
63	2019	Ram Ranjan	Assessing the impacts of mining on deforestation in India	Sand, coal, and iron mining have had the most significant impact on deforestation in India.	Q	(Ranjan 2019)
64	2019	Ruokonen	Investigating environmental approaches in mining	Accepting social and environmental obligations is important in strengthening mining companies' business.	Qu	(Ruokonen and Temmes 2019)
65	2019	Amirshenava	Presenting a model for evaluating sustainability indicators	To validate the model, it was evaluated in two iron ore mines, Golgohar and Sangan. The results showed that the Golgohar iron ore mine, with 38% sustainability, and the Sangan iron ore mine, with 46% stability, have moderate sustainability.	S	(Amirshenava and Osanloo 2019)
66	2019	Aznar-Sánchez	Analysis and innovations aimed at improving sustainability in mining activities	The priorities of the articles presented in sustainable development are reducing energy consumption and increasing the use of renewable resources.	Q	(Aznar-Sánchez et al. 2019)
67	2019	Tajvidi Asr	The relationship between mining activity and sustainable development	Mining projects can be economically profitable, environmentally clean, and socially responsible.	Qu	(Asr et al. 2019)
68	2019	Márquez	The effect of strict implementation of orders related to sustainable development in mining activity	Mining directly impacts job creation indicators, reducing poverty and hunger, and has serious challenges in gender equality indicators and climate activities.	Qu	(Márquez et al. 2019)
69	2019	Monteiro			Qu	(Monteiro, da Silva, and Neto 2019)
70	2020	Andrews	Providing a framework for examining the role of sustainable development in gold mines	The presented framework helps the government to better assess the impacts of mining before starting a project. Second, it will establish the fiduciary role of the government in the long-term development of society. Third, it provides a benchmark or leverage for negotiating mineral agreements based on sustainable development principles.	Qu	(Andrews and Essah 2020)

No	Year	First Author	Main Subject	Conclusion	Method	Refrence
71	2020	Hirons	The role of small-scale mining on sustainable development indicators	The small-scale mining sector is linked to the United Nations' Sustainable Development Goals in ways that both support and undermine their achievement.	Qu	(Hirons 2020)
72	2021	Endl	Access to raw materials according to sustainable development goals	Almost all innovation concepts had impacts on sustainable development goals separately.	Q	(Endl et al. 2019)
73	2021	Kinyondo	Investigating the interaction between the formalization of small-scale mining and negative environmental impacts in Tanzania	The regulations established in this country with small-scale mining were many contradictions because the implementation of the laws was concentrated only in certain parts of the country, and the environmental awareness among the miners was low.	Qu	(Kinyondo and Huggins 2021)
74	2021	Laing	Creating a model to assess the environmental and social impacts of small-scale mining	Small-scale mining has acted as a vital driver in reducing poverty and helping the country progress on the Sustainable Development Goals related to poverty and economic growth. However, it has caused water pollution and deforestation, which is against sustainable development goals.	S	(Laing and Moonsammy 2021)
75	2021	Maconachie	Investigating changes in sustainable development indicators in mining activity in Sierra Leone	Sierra Leone's legislative, policy, and regulatory reforms, and decentralization of the mining licensing process, have helped the development of small-scale mining in the country.	Qu	(Maconachie and Conteh 2021)
76	2021	Ekrami	Detection of heavy metals in soil using nanotechnology	Providing a set of nano-based materials to find heavy metals in the soil.	Qu	(Ekrami et al. 2021)
77	2022	Tao	Evaluating the impact of coal production on the environment	The results showed environmental pollution, freshwater pollution, climate change, and human contamination due to coal mining in China.	Qu	(Tao et al. 2022)

Q: Quantitative method

Qu: Qualitative method

S: Semi-quantitative method

4- Discussion

This leads to significant environmental impacts, including deforestation, soil degradation, and water pollution. These environmental impacts can negatively affect local communities, including the loss of agricultural land and a decline in air and water quality. Additionally, tailings dams have the potential to fail and cause catastrophic environmental disasters, such as the recent failures in Brazil and Canada. To mitigate the environmental impacts of open-pit mining, companies, and governments need to implement best practices for tailings management, such as using dry stacking instead of damming and ensuring that proper closure and rehabilitation plans are in place for mining sites. It is also important to consider alternative mining methods with lower environmental impacts, such as underground mining. Indeed, open-pit mining negatively impacts the environment due to the creation of large waste material and the need for land for tailings, dump sites, and dams. These impacts can cause significant damage to the ecosystem, wildlife, and water sources. It is important to implement sustainable mining practices that reduce environmental impacts and promote post-operational land use to mitigate these impacts. This includes proper waste management, reforestation, rehabilitation of damaged areas, and restoration of water sources. Additionally, incorporating sustainable development goals into mining operations can help to balance economic, environmental, and social objectives and ensure that all stakeholders share the benefits of mining.

4.1- Analysis of sustainable development literature review from the beginning

Based on Figure 2, the cooperation of researchers from different countries to publish articles in the field of sustainable development in mine is shown in Figure 3. The connection of articles in direct references to each other with a limit of at least ten citations for Each article is shown in Figure 4. Figure 5 shows the most important keywords used by researchers with a limit of at least 25 times using the desired word. Figure 6 shows the relationship of keywords used in articles published in the field of sustainable development in mining with a limit of at least 25 repetitions.

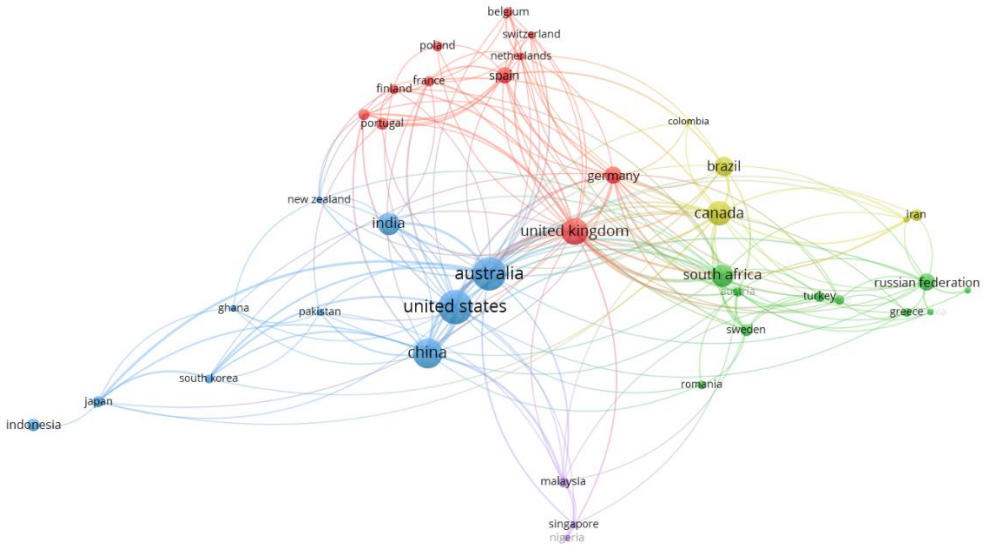

Figure 3: cooperation of researchers from different countries to publish articles in the field of sustainable development in mine (The size of the circles indicates the number of articles published on sustainable development in mining activities. The size of the links indicates the number of collaborations between countries' researchers.)

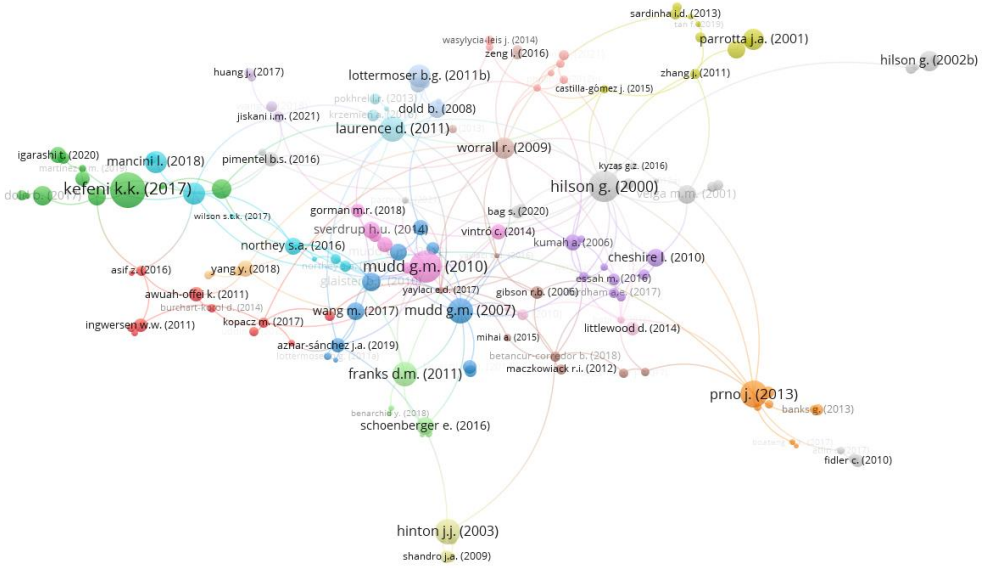

Figure 4: The connection of articles in direct references to each other (The size of the circles indicates the number of citations of each article. The size of the links indicates the number of references of each article to each other)

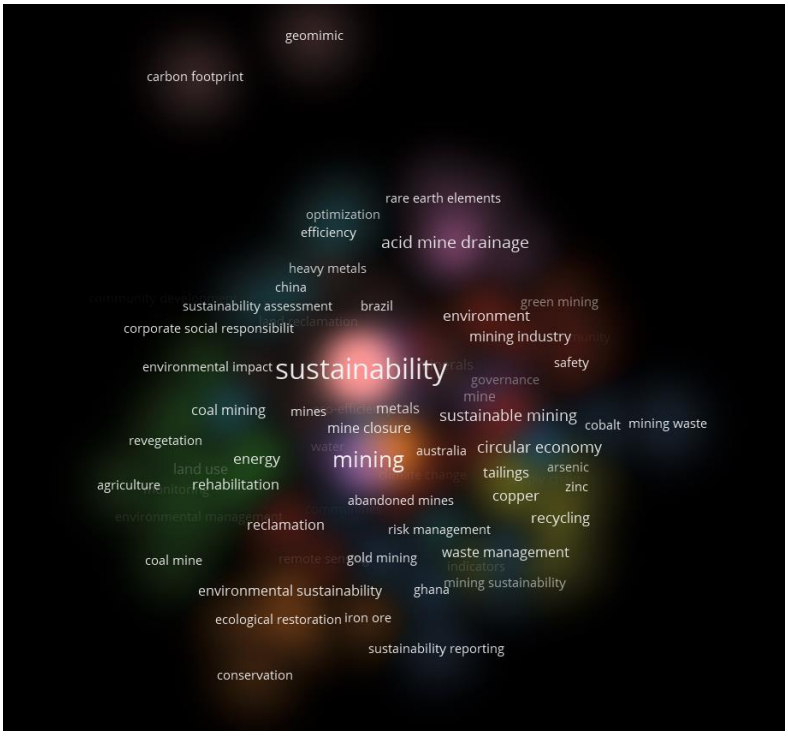

Figure 5: the most important keywords used by researchers on sustainable development in mining activities

According to Figure 5, it was observed that some new parameters should be added to sustainable assessment models due to the increase in sustainable development knowledge and technological progress. For example, we can mention the Internet of Things, renewable energy, phytoremediation, and robotics in mining. Today, these parameters are mentioned in sustainability analysis, but these parameters are not mentioned in sustainable assessment models.

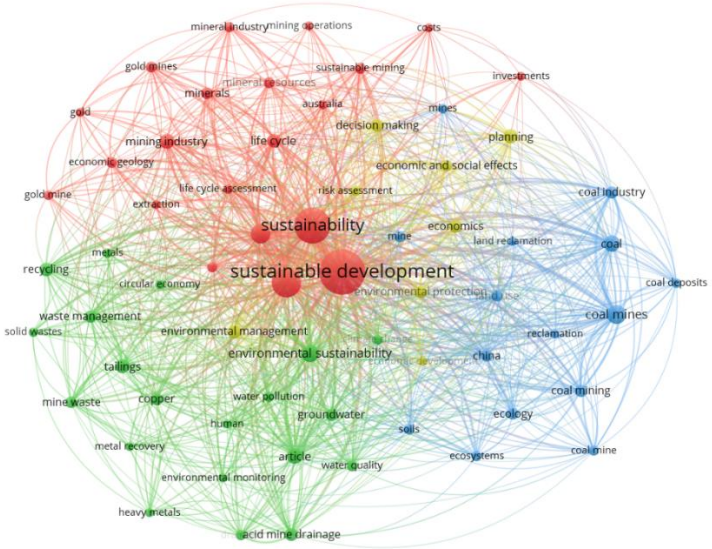

Figure 6: relationship of keywords used in articles published in the field of sustainable development in mining (The size of the circles indicates the repetition of words. The size of the links indicates the number of times words are used together.)

4.2- Analysis of the present study

In the present study, 77 articles on sustainable development were reviewed. In terms of the focus of the reviewed articles, it was found that most of the articles focused on improving the environmental aspect of sustainable development in mining operations. The main topics of discussion were the use of appropriate technology, waste management strategies, and regulations to minimize the negative impacts of mining on the environment. The need for collaboration between stakeholders such as governments, mining companies, and local communities was also emphasized to achieve a balance between economic benefits and environmental protection. In addition, the articles highlighted the importance of considering the social and economic aspects of sustainable development in mining, as these two indicators directly impact the well-being of the local community and the economy of the country. The creation of jobs, poverty reduction and support for local communities through social programs were among the topics discussed. Overall, the results of the reviewed articles suggest that a holistic approach is needed to achieve sustainable development in the mining sector. This approach should consider all three aspects of sustainable development – the environment, economy, and society – and strive to balance economic benefits, environmental protection, and social well-being.

These articles have assessed sustainable development through three general approaches: quantitative, semi-quantitative, and qualitative. The quantitative method has been used to measure the environmental indicator rather than the other two indicators since it is suitable for conducting experiments and analyzing samples collected from the environment. Among these methods, the qualitative method is low reliability for assessing the level of sustainability as it mainly depends on expert opinions; moreover, this method requires a lot of time and money (But the qualitative method is one of the best methods to investigate the effects of a parameter on sustainable development indicators). On the contrary, the semi-quantitative method relies on decision-making that combines statistical analysis and expert opinions. The semi-quantitative method usually provides reliable results and needs the least time and money compared to the other two methods.

In conclusion, sustainable development in the mining industry is a complex issue that requires a multi-dimensional approach. The semi-quantitative method is the most commonly used method for assessing sustainability in mining activities. However, due to advancements in technology, changes in regulations, and growing awareness of health and safety concerns, it is necessary to continuously revise the parameters and models used in assessing sustainability in the industry. A robust and updated assessment model will help ensure that mining activities are carried out to balance economic, social, and environmental goals while safeguarding the well-being of workers and preserving natural resources for future generations.

The present study's data revealed that the number of articles using the quantitative method was much higher than the number of articles using the other two methods. To be exact, 44% of the reviewed articles were undertaken quantitatively. It was found that 38% and 18% of articles were performed qualitatively and semi-quantitatively, respectively. The results concerning the types of methods used in the reviewed articles are presented in Table 5 (But among the 250 primary articles studied, 42 percent (105 articles) were quantitative, 33 percent (83 article) and 25 percent (62 articles) were qualitative and semi-quantitative, respectively). Since the quantitative method was often utilized to measure the environmental indicator, it can be concluded that the researchers have been more inclined to study the environmental indicator than the social or economic indicators.

Table 5: Number of articles under study by the method of study

Studies type	Number	Percentage
Qualitative	29	38
Semi-quantitative	14	18
Quantitative	34	44
Total	77	100

The reviewed articles have primarily focused on the effects of mines with heavy metals on the environment. The environmental impacts of copper, iron, zinc, lead, uranium, antimony, coal, sulfur, gold, silver, cobalt, nickel, cadmium, lime, mercury, gypsum, and pyrite released by mining have been examined. Based on the information obtained, the level of pollution induced by the mines of these heavy metals was more than that induced by the mines of other minerals and elements.

Among the sustainable development indicators, the only indicator that can be assessed quantitatively and experimentally is the environmental indicator. It involves taking samples and measuring the emission of pollutants and heavy elements into the environment in these samples. The amounts of elements emitted in the air suspended solid particles in water, and the pH level of water can also be quantified through experiments.

Among the reviewed articles, 5, 27, and 45 were published from 1985 to December 1999, 2000 to December 2009, and 2010 to January 2022, respectively (Figure 7 and Table 6).

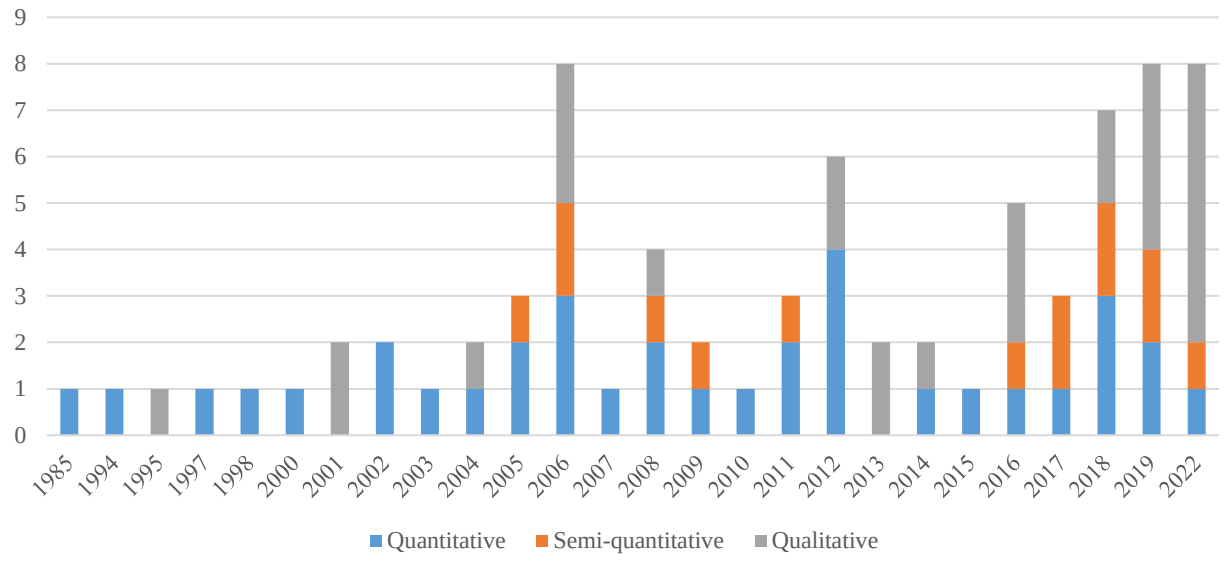

Figure 7: Cumulative diagram of reviewed articles by year and method

Table 6: Number of articles on sustainable development by the year

Year	Number
From 1985- December 1999	5
From 2000- December 2009	27
From 2010-January 2022	45
Total articles reviewed	77

In recent years, qualitative research has received more attention than quantitative and semi-quantitative research. Researchers' greater inclination toward the qualitative method can be attributed to a low degree of innovation in sustainable development assessment through the quantitative method and an assortment of articles and sustainable development models using the semi-quantitative method. Hence, it is required to develop more effective quantitative and semi-quantitative models. Additionally, owing to a growing awareness of the close relationship between mining activities and sustainable development, mining communities are currently seeking effective solutions to increase the positive effects of mining and lessen its negative impacts. Finding such solutions seems more viable via qualitative research.

One of the most popular topics in recent years has been small-scale mining. As obvious, the economy of countries and smaller communities (such as cities) highly relies on mining, including small-scale mining. Nonetheless, there is a lack of strategic and effective regulations to advance the sustainable development goals in small-scale mines. Therefore, investigating the effects of small-scale mining on sustainable development indicators has received tremendous attention in

improving this condition. More studies should be undertaken more seriously and efficiently in this area.

In Figure 8, the growing importance of sustainable development for the global community is quite evident. Figure 3 illustrates an increasing number of publications on sustainable development from 1985 to January 2022.

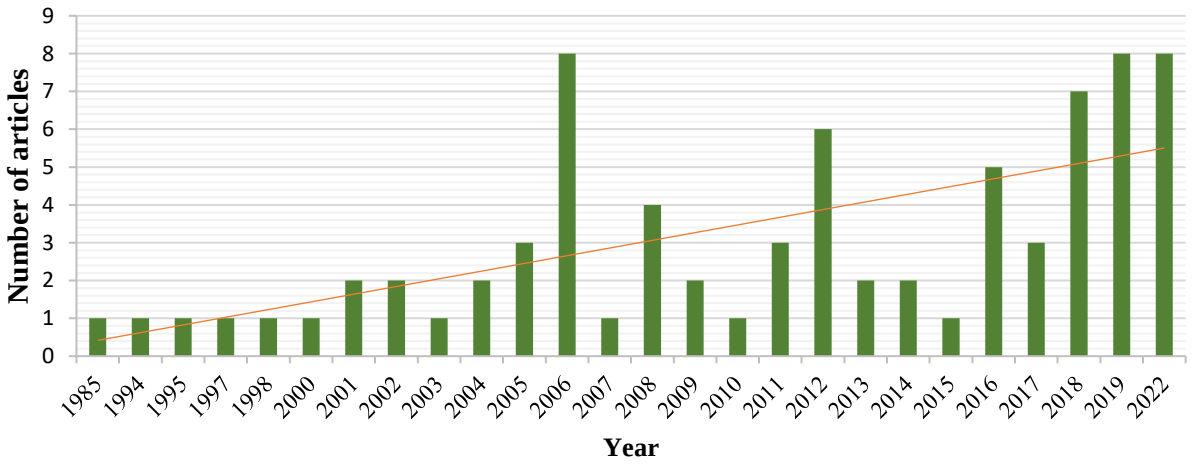

Figure 8: Growing number of publications on sustainable development

The formal definition of sustainable development offered in 1992 can be one of the reasons for a surge in articles on sustainable development. As the analysis of the articles indicates, all the methods mentioned above have increasingly been used to assess sustainable development in recent years. Numerous efforts have been made to achieve an all-inclusive method of sustainable development due to providing in-depth analysis and assessing all parameters of an indicator or all indicators. The quantitative method is the third most frequent (Figure 11). The qualitative method also had a significant growth rate from 2010 to January 2022 (Figure 9). This method is the most frequently employed since to achieve a comprehensive, general, and useful, sustainable development plan; it is required to thoroughly analyze all parameters in all indicators. This method is not expensive. The studies following this method are primarily case studies and have mainly evaluated the social indicator. The semi-quantitative method is the second most frequent due to being comprehensive and addressing all the sustainable development indicators (Figure 10). It largely applies to the environmental indicator, and many studies have focused on it.

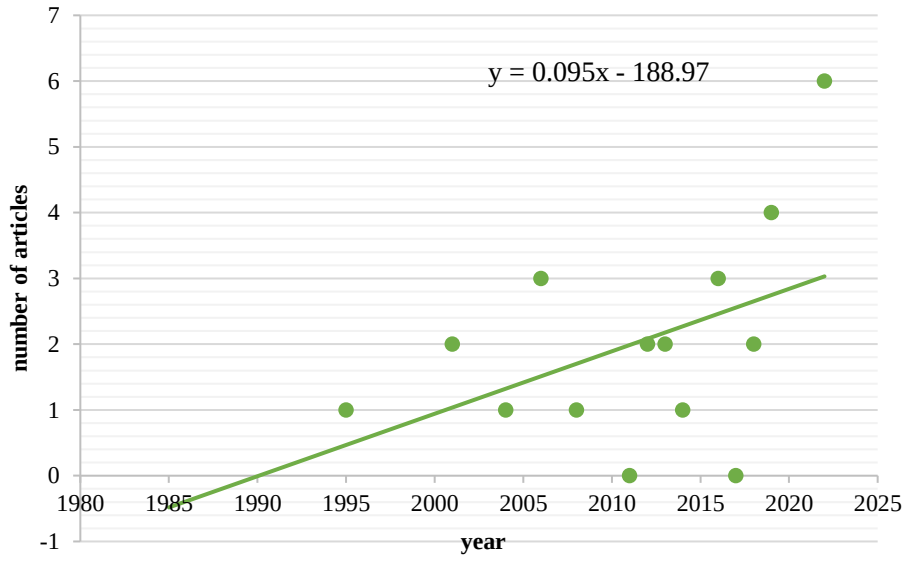

Figure 9: Growth rate of articles studied in quantitative method

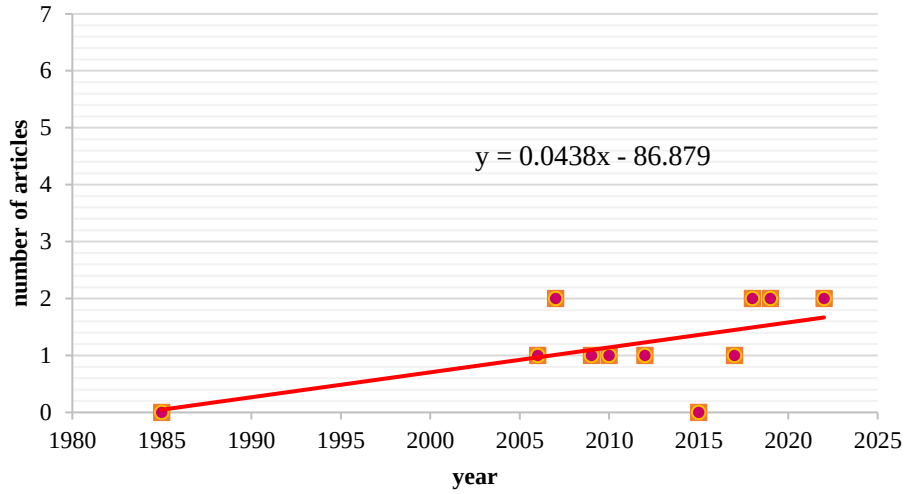

Figure 10: Growth rate of articles studied in semi-quantitative method

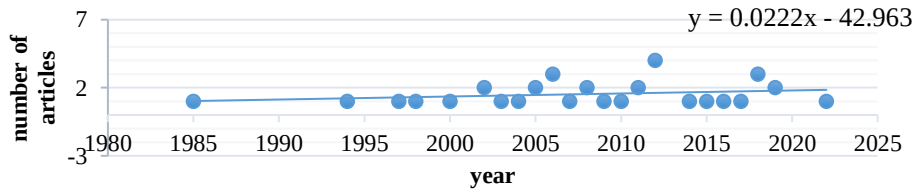

Figure 11: Growth rate of articles studied in quantitative method

Today, the growth of technology and the enhancement of knowledge about sustainable development have introduced some factors that can be considered new parameters of sustainable development indicators. Owing to the development of technology in mining activities, it may also be necessary to propose new main indicators of sustainable development in mining. Newly introduced indicators can be introduced as independent indicators, with two main impacting factors (economic-social, economic-environmental, and socio-environmental indicators) or with three main impacting factors (economic, social, and environmental dimensions). The drawbacks and upsides of the three methods (quantitative, semi-quantitative, and qualitative) employed to evaluate sustainable development are provided in Table 7.

Table 7: Advantages and disadvantages of methods used to assess sustainable development

Method	Advantages	Disadvantages
Quantitative	High reliability, More accurate investigation of indicators	High cost, time-consuming, Not much applicable to economic and social indicators
Semi-quantitative	Use of expert opinion, Acceptable reliability, Possibility of comparing it with other decision-making methods	Less reliable than the quantitative method, Ignorance or underestimation of some parameters
Qualitative	Highly applicable to social indicators, Considering all dimensions in each indicator, Ability to check the expected parameter on sustainable development indicators	Low reliability for assessing the level of sustainability, having little application in mines

A summary of all seven articles reviewed in this study is provided in Figure 12.

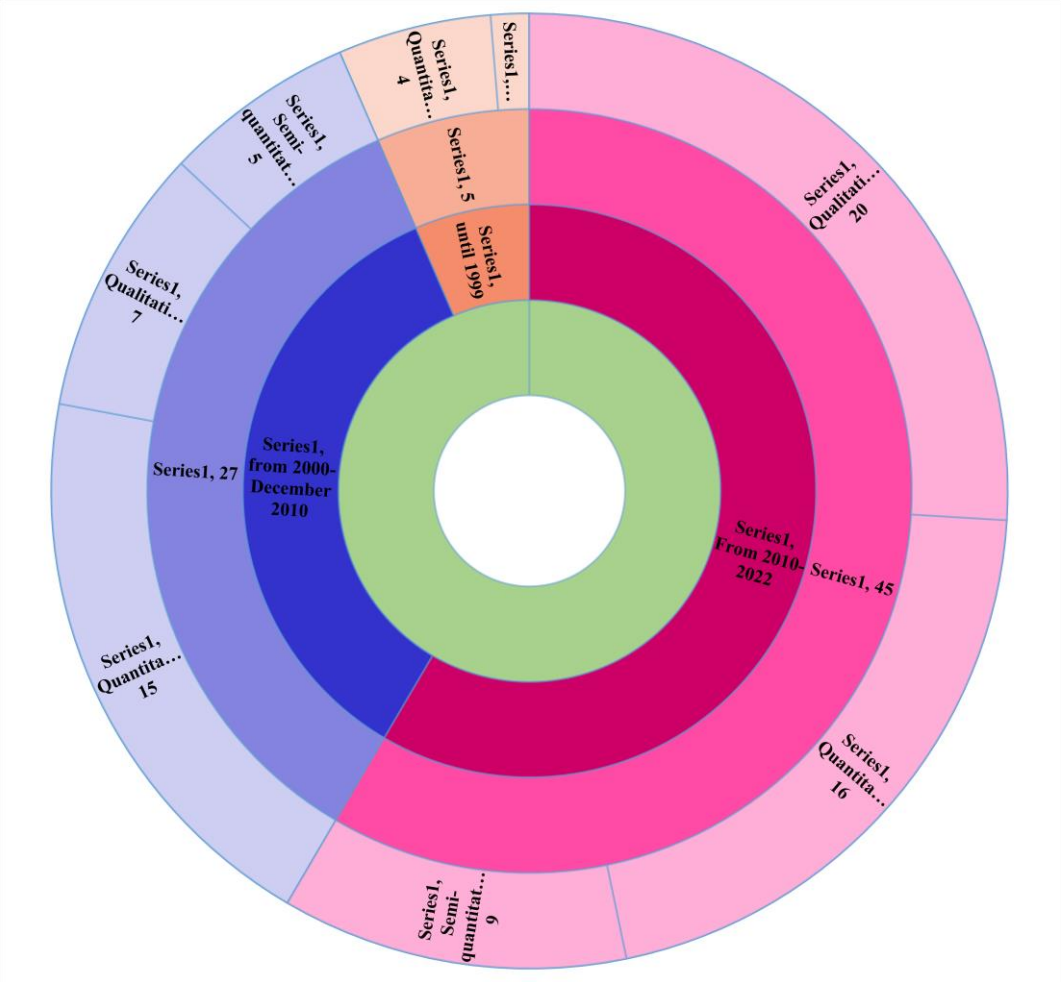

Figure 12: Summary of articles under study

5- Conclusion

The mining industry significantly impacts the environment and local communities, and sustainable development practices aim to minimize these impacts while ensuring economic viability and social well-being. This includes minimizing waste and pollution, protecting wildlife and ecosystems, promoting local economic development, and improving the living standards of affected communities. Implementing these practices also helps build a positive reputation for the mining industry and increase public support for its operations review of 77 articles on sustainable development indicators in mining is an important contribution to the field of sustainable mining. The analysis of these articles provides valuable insights into the current state of knowledge and practice regarding sustainable development in mining. The review results could be used to identify gaps in the existing research and guide future research efforts. Additionally, the review's findings could inform policy decisions and guide the development of sustainable mining practices. Overall,

the review highlights the importance of continued efforts to promote sustainable development in the mining industry.

Therefore, the semi-quantitative method, which combines the advantages of both the qualitative and quantitative methods, is considered the most suitable for evaluating sustainable development in mining. The semi-quantitative method provides a practical and cost-effective way to assess sustainable mining development while still providing valuable insights into the various indicators and their impacts. This method also allows for greater flexibility in the analysis, as it can be adapted to different mining operations and regions, taking into account local conditions and constraints. Overall, using the semi-quantitative method in evaluating sustainable development in mining is crucial for promoting sustainability in this industry and ensuring a better future for the environment and communities. On the contrary, The results of the review indicate that the semi-quantitative method is becoming increasingly popular for evaluating sustainable development in mining. The semi-quantitative method provides a good balance between the results' reliability and the evaluation's time and cost. The large proportion of articles that use this method suggests that it is well-regarded among researchers and practitioners in the field. On the other hand, using quantitative methods is also significant, especially in assessing environmental indicators, where taking samples and conducting experiments is important to measure the impact of mining on the environment accurately. The use of qualitative methods is less common but still provides valuable insights into the social and economic aspects of sustainable development in mining. Overall, the use of a combination of methods, including semi-quantitative, quantitative, and qualitative, can provide a comprehensive and robust evaluation of sustainable development in mining. The variety of minerals studied in the 77 articles reviewed highlights the broad impact mining has on the environment and the need for a comprehensive evaluation of sustainable development in this industry. The study of 20 pollutants in the samples and the pH level of the water provides valuable information about the potential impact of mining operations on the environment. These indicators help to assess the impact of mining on water quality, which is an important aspect of sustainable development, as it affects not only the environment but also human health and the well-being of local communities. Including these environmental indicators in the evaluation of sustainable development in mining helps ensure that the industry operates in an environmentally responsible manner. The study results the show that mining has both positive and negative impacts on the environment, society, and economy. On the one hand, mining has reduced unemployment and improved welfare and life expectancy in the region. Foreign investment has also led to language and technology transfer, which can positively impact the local community. Additionally, mining has improved the living standards in the region and brought a business boom, job creation, and increased regional liquidity. On the other hand, mining has also caused environmental pollution, which has the potential to harm the health of living organisms and humans. Although, in some cases, pollution has strengthened the soil and facilitated the growth of some plants, the long-term impacts of environmental pollution can be significant and difficult to reverse. Therefore, it is important to ensure that the positive impacts of mining are maximized, and the negative impacts are minimized. This can be achieved through the adoption of sustainable development practices

and the use of appropriate indicators to assess and track progress toward sustainability in the mining industry. Research on the effects of mining on sustainable development is on the rise, and special attention has been directed to this area of research. The increased attention on the impact of small-scale mining on sustainable development indicators reflects the growing concern about the environmental, social, and economic impacts. The rise in the use of qualitative methods in recent years suggests a growing interest in exploring the subjective experiences of communities and other stakeholders affected by small-scale mining. The semi-quantitative and quantitative methods are also widely used, providing valuable information about the environmental, social, and economic impacts of small-scale mining and the effectiveness of various sustainable development interventions. Overall, the use of a combination of methods, including qualitative, semi-quantitative, and quantitative, can provide a comprehensive and robust evaluation of the impact of small-scale mining on sustainable development indicators. This is important for promoting sustainability in this sector and ensuring a better future for the environment, communities, and the economy. The possible reasons for a surge in the publication of qualitative and semi-quantitative studies are as follows:

- Concerning the qualitative method, due to increased awareness of the complications of mining activities on the sustainable development indicators and the existence of an assortment of models for sustainable development assessment in mines, researchers have recently attempted to detect practical and effective solutions via the qualitative method to reduce the negative effects of mining and boost the positive effects of sustainable development.
- Many models have been offered for evaluating sustainable development in mines. However, there is a need to devise a comprehensive, general, accurate, and simple method to achieve sustainability. Concerning the semi-quantitative method, since both researcher and expert opinions are involved in the research process, in some cases, the importance of some parameters may be neglected. This inclusive method should thoroughly evaluate all the dimensions of sustainable development with minimum cost and time, have a high level of reliability, and be based on modern technologies used in mines.

As technology and our understanding of sustainable development evolve, it is important to continually review and update sustainable development models to ensure they are relevant and useful. As a suggestion, the integration of new and innovative concepts, such as the Internet of Things, phytoremediation, renewable energy, and environmental literacy, into sustainable development assessments can help increase the accuracy and effectiveness of these evaluations. Incorporating these new parameters into sustainable development assessment models may also help reduce uncertainty in the evaluation process and provide a more comprehensive and accurate picture of the mining industry's sustainability level. This is critical for ensuring that the industry operates in an environmentally responsible manner and for promoting sustainable development in the long term. Therefore, researchers should continue exploring new concepts and innovative approaches to sustainable development assessments to continuously improve these evaluations' accuracy and effectiveness.

References

Akabzaa, TM, TEK Armah, and BK Baneong-Yakubo. 2007. 'Prediction of acid mine drainage generation potential in selected mines in the Ashanti Metallogenic Belt using static geochemical methods', *Environmental Geology*, 52: 957-64.

Akcil, Ata, and Soner Koldas. 2006. 'Acid Mine Drainage (AMD): causes, treatment and case studies', *Journal of cleaner production*, 14: 1139-45.

Ali, Aal-e, Vladimir Strezov, Peter J Davies, and Ian Wright. 2018. 'River sediment quality assessment using sediment quality indices for the Sydney basin, Australia affected by coal and coal seam gas mining', *Science of the total environment*, 616: 695-702.

Alvarenga, Paula, Patrícia Palma, Amarilis De Varennes, and Ana C Cunha-Queda. 2012. 'A contribution towards the risk assessment of soils from the São Domingos Mine (Portugal): chemical, microbial and ecotoxicological indicators', *Environmental pollution*, 161: 50-56.

Amaral, ECS, HLP Azevedo, and AH Mendonca. 1985. 'Pre-operational environmental survey at the uranium mine and mill site, Poços de Caldas, Minas Gerais, Brazil', *Science of the total environment*, 42: 257-66.

Amiri, Ravanbakhsh, Jürgen Kretschmann, Per Nicolai Martens, and Oliver Langefeld. 2017. "Sustainable strategic management of Sangan iron ore mines in Iran." In.: Fachgruppe für Rohstoffe und Entsorgungstechnik.

Amirshenava, Sina, and Morteza Osanloo. 2018. 'Mine closure risk management: an integration of 3D risk model and MCDM techniques', *journal of cleaner production*, 184: 389-401.

———. 2019. 'A hybrid semi-quantitative approach for impact assessment of mining activities on sustainable development indexes', *Journal of cleaner production*, 218: 823-34.

Andrews, Nathan, and Marcellinus Essah. 2020. 'The sustainable development conundrum in gold mining: Exploring 'Open, Prior and Independent Deliberate Discussion'as a community-centered framework', *Resources policy*, 68: 101798.

Antoniadis, Vasileios, Sabry M Shaheen, Judith Boersch, Tina Frohne, Gijs Du Laing, and Jörg Rinklebe. 2017. 'Bioavailability and risk assessment of potentially toxic elements in garden edible vegetables and soils around a highly contaminated former mining area in Germany', *Journal of environmental management*, 186: 192-200.

Aslibekian, Olga, and Richard Moles. 2003. 'Environmental risk assessment of metals contaminated soils at silvermines abandoned mine site, Co Tipperary, Ireland', *Environmental geochemistry and health*, 25: 247-66.

Asr, Elmira Tajvidi, Reza Kakaie, Mohammad Ataei, and Mohammad Reza Tavakoli Mohammadi. 2019. 'A review of studies on sustainable development in mining life cycle', *Journal of cleaner production*, 229: 213-31.

Azapagic, Adisa. 2004. 'Developing a framework for sustainable development indicators for the mining and minerals industry', *Journal of cleaner production*, 12: 639-62.

Aznar-Sánchez, José A, Juan F Velasco-Muñoz, Luis J Belmonte-Ureña, and Francisco Manzano-Agugliaro. 2019. 'Innovation and technology for sustainable mining activity: A worldwide research assessment', *journal of cleaner production*, 221: 38-54.

Bui, Nuong Thi, Akira Kawamura, Kyoung Woong Kim, Lunchakorn Prathumratana, Tae-Heok Kim, Suk-Ho Yoon, Min Jang, Hideo Amaguchi, Duong Du Bui, and Ngoc Tu Truong. 2017. 'Proposal of an indicator-based sustainability assessment framework for the mining sector of APEC economies', *Resources policy*, 52: 405-17.

Campos, Michelle Burato, Heliana de Azevedo, Marcos Roberto Lopes Nascimento, Cláudio Vítor Roque, and Suzelei Rodgher. 2011. 'Environmental assessment of water from a uranium mine (Caldas, Minas Gerais State, Brazil) in a decommissioning operation', *Environmental earth sciences*, 62: 857-63.

Castilla, Juan C. 1996. 'Copper mine tailing disposal in northern Chile rocky shores: Enteromorpha compressa (Chlorophyta) as a sentinel species', *Environmental monitoring and assessment*, 40: 171-84.
Cheng, Xianfeng, Tomas Danek, Jarmila Drozdova, Qianrui Huang, Wufu Qi, Liling Zou, Shuran Yang, Xinliang Zhao, and Yungang Xiang. 2018. 'Soil heavy metal pollution and risk assessment associated with the Zn-Pb mining region in Yunnan, Southwest China', *Environmental monitoring and assessment*, 190: 1-16.
Cui, Chao-Qun, Bing Wang, Yi-Xin Zhao, Qian Wang, and Zhen-Ming Sun. 2019. 'China's regional sustainability assessment on mineral resources: Results from an improved analytic hierarchy process-based normal cloud model', *journal of cleaner production*, 210: 105-20.
DeNicola, Dean M, and Michael G Stapleton. 2002. 'Impact of acid mine drainage on benthic communities in streams: the relative roles of substratum vs. aqueous effects', *Environmental pollution*, 119: 303-15.
Dialga, Issaka. 2018. 'A sustainability index of mining countries', *Journal of cleaner production*, 179: 278-91.
Doupé, Robert G, and Alan J Lymbery. 2005. 'Environmental risks associated with beneficial end uses of mine lakes in southwestern Australia', *Mine Water and the Environment*, 24: 134-38.
Drebenstedt, Carsten. 2014. 'The Responsible Mining Concept–Contributions on the Interface between Science and Practical Needs.' in, *Mine Planning and Equipment Selection* (Springer).
Driussi, Catherine, and Janis Jansz. 2006. 'Pollution minimisation practices in the Australian mining and mineral processing industries', *Journal of cleaner production*, 14: 673-81.
Ebrahimabadi, Arash, Mahdi Pouresmaieli, Alireza Afradi, Esmaeil Pouresmaeili, and Sahand Nouri. 2018. 'Comparing two methods of PROMETHEE and Fuzzy TOPSIS in selecting the best plant species for the reclamation of Sarcheshmeh copper mine', *Asian Journal of Water, Environment and Pollution*, 15: 141-52.
Edraki, Mansour, Thomas Baumgartl, Emmanuel Manlapig, Dee Bradshaw, Daniel M Franks, and Chris J Moran. 2014. 'Designing mine tailings for better environmental, social and economic outcomes: a review of alternative approaches', *journal of cleaner production*, 84: 411-20.
Ekrami, Elena, Mahdi Pouresmaieli, Elham sadat Hashemiyoon, Negin Noorbakhsh, and Matin Mahmoudifard. 2022. 'Nanotechnology: a sustainable solution for heavy metals remediation', *Environmental Nanotechnology, Monitoring & Management*, 18: 100718.
Ekrami, Elena, Mahdi Pouresmaieli, Parvin Shariati, and Matin Mahmoudifard. 2021. 'A review on designing biosensors for the detection of trace metals', *Applied Geochemistry*: 104902.
Endl, Andreas, Michael Tost, Michael Hitch, Peter Moser, and Susanne Feiel. 2019. 'Europe's mining innovation trends and their contribution to the sustainable development goals: Blind spots and strong points', *Resources policy*: 101440.
Environment, World Commission on, Development, and Gro Harlem Brundtland. 1987. *Presentation of the Report of World Commission on Environment and Development to African and International and Non-governmental Organizations... June 7, 1987, Nairobi, Kenya* (World Commission on Environment and Development).
Farahani, Hossein, and Shadi Bayazidi. 2018. 'Modeling the assessment of socio-economical and environmental impacts of sand mining on local communities: A case study of Villages Tatao River Bank in North-western part of Iran', *Resources policy*, 55: 87-95.
Fonseca, Alberto, Mary Louise McAllister, and Patricia Fitzpatrick. 2013. 'Measuring what? A comparative anatomy of five mining sustainability frameworks', *Minerals Engineering*, 46: 180-86.
———. 2014. 'Sustainability reporting among mining corporations: a constructive critique of the GRI approach', *journal of cleaner production*, 84: 70-83.
Gibson, Robert B. 2006a. 'Sustainability assessment and conflict resolution: Reaching agreement to proceed with the Voisey's Bay nickel mine', *Journal of cleaner production*, 14: 334-48.

———. 2006b. 'Sustainability assessment: basic components of a practical approach', *Impact Assessment and Project Appraisal*, 24: 170-82.
Giurco, Damien, and Carlia Cooper. 2012. 'Mining and sustainability: asking the right questions', *Minerals Engineering*, 29: 3-12.
Gray, NF. 1997. 'Environmental impact and remediation of acid mine drainage: a management problem', *Environmental Geology*, 30: 62-71.
Gray, NF, and E Delaney. 2008. 'Comparison of benthic macroinvertebrate indices for the assessment of the impact of acid mine drainage on an Irish river below an abandoned Cu–S mine', *Environmental pollution*, 155: 31-40.
Gupta, Pankaj, Mukesh Kumar Mehlawat, Usha Aggarwal, and V Charles. 2018. 'An integrated AHP-DEA multi-objective optimization model for sustainable transportation in mining industry', *Resources policy*: 101180.
Hacking, Theo, and Peter Guthrie. 2008. 'A framework for clarifying the meaning of Triple Bottom-Line, Integrated, and Sustainability Assessment', *Environmental Impact Assessment Review*, 28: 73-89.
Hadzi, George Yaw, David Kofi Essumang, and Godwin A Ayoko. 2018. 'Assessment of contamination and health risk of heavy metals in selected water bodies around gold mining areas in Ghana', *Environmental monitoring and assessment*, 190: 1-17.
Hartman, Howard L, Scott G Britton, Jan M Mutmansky, Donald W Gentry, W Joseph Schlitt, Michael Karmis, and Madan M Singh. 1992. *SME mining engineering handbook* (Society for Mining, Metallurgy, and Exploration Denver).
Herr, Claudia, and NF Gray. 1997. 'Metal contamination of riverine sediments below the Avoca mines, south east Ireland', *Environmental geochemistry and health*, 19: 73-82.
Hirons, Mark. 2020. 'How the Sustainable Development Goals risk undermining efforts to address environmental and social issues in the small-scale mining sector', *Environmental Science & Policy*, 114: 321-28.
Huertas, José I, María E Huertas, Sebastián Izquierdo, and Enrique D González. 2012. 'Air quality impact assessment of multiple open pit coal mines in northern Colombia', *journal of environmental management*, 93: 121-29.
Jarvis, Adam P, and Paul L Younger. 2000. 'Broadening the scope of mine water environmental impact assessment: a UK perspective', *Environmental Impact Assessment Review*, 20: 85-96.
Jha-Thakur, Urmila, Thomas B Fischer, and Asha Rajvanshi. 2009. 'Reviewing design stage of environmental impact assessment follow-up: Looking at the open cast coal mines in India', *Impact Assessment and Project Appraisal*, 27: 33-44.
Khan, R, SH Israili, H Ahmad, and A Mohan. 2005. 'Heavy metal pollution assessment in surface water bodies and its suitability for irrigation around the Neyevli lignite mines and associated industrial complex, Tamil Nadu, India', *Mine Water and the Environment*, 24: 155-61.
Kim, Ju-Yong, Kyoung-Woong Kim, Joo Sung Ahn, Ilwon Ko, and Cheol-Hyo Lee. 2005. 'Investigation and risk assessment modeling of As and other heavy metals contamination around five abandoned metal mines in Korea', *Environmental geochemistry and health*, 27: 193-203.
Kim, Ju-Yong, Kyoung-Woong Kim, Jong-Un Lee, Jin-Soo Lee, and Jenny Cook. 2002. 'Assessment of As and heavy metal contamination in the vicinity of Duckum Au-Ag mine, Korea', *Environmental geochemistry and health*, 24: 213-25.
King, BM. 1998. "Impact of rehabilitation and closure costs on production rate and cut-off grade strategy." In *APCOM'98 (London, 19-23 April 1998)*, 617-29.
Kinyondo, Abel, and Chris Huggins. 2021. 'State-led efforts to reduce environmental impacts of artisanal and small-scale mining in Tanzania: Implications for fulfilment of the sustainable development goals', *Environmental Science & Policy*, 120: 157-64.

Kitula, AGN. 2006. 'The environmental and socio-economic impacts of mining on local livelihoods in Tanzania: A case study of Geita District', *journal of cleaner production*, 14: 405-14.
Kolotzek, Christoph, Christoph Helbig, Andrea Thorenz, Armin Reller, and Axel Tuma. 2018. 'A company-oriented model for the assessment of raw material supply risks, environmental impact and social implications', *journal of cleaner production*, 176: 566-80.
Kumah, Abraham. 2006. 'Sustainability and gold mining in the developing world', *journal of cleaner production*, 14: 315-23.
Laing, Timothy, and Stephan Moonsammy. 2021. 'Evaluating the impact of small-scale mining on the achievement of the sustainable development goals in Guyana', *Environmental Science & Policy*, 116: 147-59.
Laurence, David. 2006. 'Optimisation of the mine closure process', *Journal of cleaner production*, 14: 285-98.
———. 2011. 'Establishing a sustainable mining operation: an overview', *Journal of cleaner production*, 19: 278-84.
Li, Zhiyuan, Zongwei Ma, Tsering Jan van der Kuijp, Zengwei Yuan, and Lei Huang. 2014. 'A review of soil heavy metal pollution from mines in China: pollution and health risk assessment', *Science of the total environment*, 468: 843-53.
Maconachie, Roy, and Felix Conteh. 2021. 'Artisanal mining policy reforms, informality and challenges to the Sustainable Development Goals in Sierra Leone', *Environmental Science & Policy*, 116: 38-46.
Márquez, Ana Julieth Calderón, Paulo Cezar Cassettari Filho, Emília Wanda Rutkowski, and Ricardo de Lima Isaac. 2019. 'Landfill mining as a strategic tool towards global sustainable development', *journal of cleaner production*, 226: 1102-15.
Monjezi, Masoud, K Shahriar, Hesam Dehghani, and F Samimi Namin. 2009. 'Environmental impact assessment of open pit mining in Iran', *Environmental Geology*, 58: 205-16.
Monteiro, Nathalie Barbosa Reis, Elaine Aparecida da Silva, and José Machado Moita Neto. 2019. 'Sustainable development goals in mining', *journal of cleaner production*, 228: 509-20.
Moreno-Jiménez, Eduardo, Concepción García-Gómez, Ana Lourdes Oropesa, Elvira Esteban, Amparo Haro, Ramón Carpena-Ruiz, Jose Vicente Tarazona, Jesus Manuel Peñalosa, and María Dolores Fernández. 2011. 'Screening risk assessment tools for assessing the environmental impact in an abandoned pyritic mine in Spain', *Science of the total environment*, 409: 692-703.
Morrison-Saunders, Angus, MP McHenry, A Rita Sequeira, Phill Gorey, Hudson Mtegha, and David Doepel. 2016. 'Integrating mine closure planning with environmental impact assessment: challenges and opportunities drawn from African and Australian practice', *Impact Assessment and Project Appraisal*, 34: 117-28.
Mudd, Gavin M. 2008. 'Sustainability reporting and water resources: a preliminary assessment of embodied water and sustainable mining', *Mine Water and the Environment*, 27: 136-44.
Neves, O, and MJ Matias. 2008. 'Assessment of groundwater quality and contamination problems ascribed to an abandoned uranium mine (Cunha Baixa region, Central Portugal)', *Environmental Geology*, 53: 1799-810.
Phillips, Jason. 2012. 'Using a mathematical model to assess the sustainability of proposed bauxite mining in Andhra Pradesh, India from a quantitative-based environmental impact assessment', *Environmental earth sciences*, 67: 1587-603.
Pouresmaieli, Mahdi, Mohammad Ataei, Pegah Forouzandeh, Paridokht Azizollahi, and Matin Mahmoudifard. 2022. 'Recent Progress on Sustainable Phytoremediation of Heavy Metals from Soil', *Journal of Environmental Chemical Engineering*: 108482.
Pouresmaieli, Mahdi, Mohammad Ataei, and Amirhossein Taran. 2022. 'Future mining based on internet of things (IoT) and sustainability challenges', *International Journal of Sustainable Development & World Ecology*: 1-18.

Pouresmaieli, Mahdi, and Morteza Osanloo. 2019a. "Establishing a Model to Reduce the Risk of Premature Mine Closure." In *IOP Conference Series: Earth and Environmental Science*, 012005. IOP Publishing.
———. 2019b. "A Valuation Approach to Investigate the Sustainability of Sorkhe-Dizaj Iron Ore Mine of Iran." In *International Symposium on Mine Planning & Equipment Selection*, 431-46. Springer.
Pourret, Olivier, Bastien Lange, Jessica Bonhoure, Gilles Colinet, Sophie Decrée, Grégory Mahy, Maxime Séleck, Mylor Shutcha, and Michel-Pierre Faucon. 2016. 'Assessment of soil metal distribution and environmental impact of mining in Katanga (Democratic Republic of Congo)', *Applied Geochemistry*, 64: 43-55.
Prno, Jason, and D Scott Slocombe. 2012. 'Exploring the origins of 'social license to operate'in the mining sector: Perspectives from governance and sustainability theories', *Resources policy*, 37: 346-57.
Rakotondrabe, Felaniaina, Jules Remy Ndam Ngoupayou, Zakari Mfonka, Eddy Harilala Rasolomanana, Alexis Jacob Nyangono Abolo, and Andrew Ako Ako. 2018. 'Water quality assessment in the Bétaré-Oya gold mining area (East-Cameroon): multivariate statistical analysis approach', *Science of the total environment*, 610: 831-44.
Ranjan, Ram. 2019. 'Assessing the impact of mining on deforestation in India', *Resources policy*, 60: 23-35.
Rodríguez, L, E Ruiz, J Alonso-Azcárate, and J Rincón. 2009. 'Heavy metal distribution and chemical speciation in tailings and soils around a Pb–Zn mine in Spain', *Journal of environmental management*, 90: 1106-16.
Roychoudhury, Alakendra N, and Michael F Starke. 2006. 'Partitioning and mobility of trace metals in the Blesbokspruit: Impact assessment of dewatering of mine waters in the East Rand, South Africa', *Applied Geochemistry*, 21: 1044-63.
Ruokonen, Eeva, and Armi Temmes. 2019. 'The approaches of strategic environmental management used by mining companies in Finland', *Journal of cleaner production*, 210: 466-76.
Sheoran, AS, and V Sheoran. 2006. 'Heavy metal removal mechanism of acid mine drainage in wetlands: a critical review', *Minerals Engineering*, 19: 105-16.
Singh, Abhay Kumar, MK Mahato, B Neogi, BK Tewary, and A Sinha. 2012. 'Environmental geochemistry and quality assessment of mine water of Jharia coalfield, India', *Environmental earth sciences*, 65: 49-65.
Singh, Abhay Kumar, Mukesh K Mahato, Babita Neogi, and KK Singh. 2010. 'Quality assessment of mine water in the Raniganj coalfield area, India', *Mine Water and the environment*, 29: 248-62.
Slootweg, Roel, Frank Vanclay, and Marlies Van Schooten. 2001. 'Function evaluation as a framework for the integration of social and environmental impact assessment', *Impact Assessment and Project Appraisal*, 19: 19-28.
Spurgeon, DJ, SP Hopkin, and DT Jones. 1994. 'Effects of cadmium, copper, lead and zinc on growth, reproduction and survival of the earthworm Eisenia fetida (Savigny): assessing the environmental impact of point-source metal contamination in terrestrial ecosystems', *Environmental pollution*, 84: 123-30.
Steinemann, Anne. 2001. 'Improving alternatives for environmental impact assessment', *Environmental Impact Assessment Review*, 21: 3-21.
Suopajärvi, Leena, Gregory A Poelzer, Thomas Ejdemo, Elena Klyuchnikova, Elena Korchak, and Vigdis Nygaard. 2016. 'Social sustainability in northern mining communities: A study of the European North and Northwest Russia', *Resources policy*, 47: 61-68.
Tao, Ming, Wenqing Cheng, Kemi Nie, Xu Zhang, and Wenzhuo Cao. 2022. 'Life cycle assessment of underground coal mining in China', *Science of the total environment*, 805: 150231.

Wang, Xinyi, Tiantian Wang, Qi Wang, Xiaoman Liu, Renzheng Li, and BaoJin Liu. 2017. 'Evaluation of floor water inrush based on fractal theory and an improved analytic hierarchy process', *Mine Water and the Environment*, 36: 87-95.
Zvarivadza, T. 2018. 'Artisanal and Small-Scale Mining as a challenge and possible contributor to Sustainable Development', *Resources policy*, 56: 49-58.