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Research article

Assessment of key socio-economic and environmental challenges in the mining industry: Implications for resource policies in emerging economies

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ABSTRACT

This paper seeks to develop a framework to identify, analyse, and assess the mining industry's key challenges in terms of environmental, operational, and social issues. For each issue, 15 challenges have been identified from experts' opinions and from the relevant literature; each is examined in a real-world industrial setting. South India's mining industry is utilized to categorize and to determine crucial challenges based on an identification of their causal relationships. A fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) is used to assess and rank the challenges of each issue. Results reveal that climate change, lack of availability of capital, and unfair wages are the top challenges in the environmental, operational, and social issues, respectively, in India's mining industry. The proposed method is found effective in attaining the causal relationships and ranking amongst the identified challenges. The outcomes help decision-makers and industrial managers to take remedial actions such as adopting new technologies and innovations to protect the environment, improve the operating conditions, and facilitate social benefits to resolve the mining industry's challenges.

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1. Introduction

Population growth and economic needs result in increased urbanization which, in turn, augments the demand for basic infrastructure like residential and industrial buildings. Such demand for basic infrastructure increases the need for mined products and acts as a fundamental driving force for the mining industry (Sarupria et al., 2019). The role of the mining industry is vital for the comfortable progress of humankind and the global economy. According to the International Council of Mining and Metals (ICMM), nearly 70 countries are primarily dependant on the mining industry; most of those countries are low income developing countries (https://www.icmm.com/). The contribution of the mining industry to the GDP of various countries is rated as follows: Turkey (1%), Germany (4%), USA (4.5%), Canada (7.5%), Australia (8.7%), China (13%), India (10–11%), Indonesia (7.2%), Mongolia (up to 20%), Pakistan (15%) and Russia (14%) (TMA, 2019; Gupta et al., 2018; Nurim et al., 2020; Bumochir, 2020; Ali and Rehman, 2020).

The mining industry plays a critical role in terms of a nation's economic dimension and it is a vital concern in the environmental dimension as well. Natural resource-based economic activities have expanded largely over the past few decades in both developing and developed countries (Pietrobelli et al., 2018). Overdependence on natural resources leads to its uncontrolled exploitation and results in environmental impacts such as climatic problems, emission of harmful gases, ecosystem disruption, and biodiversity loss. The mining industry is often criticized for its frequent fatalities, resource depletion, and unsustainable practices (Farjana et al., 2019). It is impossible to completely ban the mining industry since it is such a major player in the global economy, but it is possible to carry out mining activities in a sustainable manner. With environmental laws becoming more stringent across the world, the mining industry is under pressure to adopt sustainability in their industrial activities. Realizing the need to integrate sustainability in all industrial activities, stakeholders of the mining industry emphasise adopting sustainability (Cesar and Jhony, 2021).

India is the fourth-largest mineral producer next to China, Russia, and United States (IBEF, 2020), and the mining industry contributes around 2% of India's GDP (Singh et al., 2020). Beyond its

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Nomenclature

E1	Failure of mining roof from the extraction of resources
E2	Contamination of air, soil, and water
E3	Pollution of the environment from the chemicals used in extraction process
E4	Poor waste management process
E5	Environmental regulations
E6	Non-adherence to green policy
E7	Potential effect on buildings and built structures due to climate change
E8	Sinkholes formed by the methods employed for mining
E9	Energy consumption
E10	Water depletion
E11	Mineral source depletion
E12	Fossil fuel depletion
E13	Particulate matter formation by mineral dust (coarse particles) and engine emissions (fine particles)
E14	Greenhouse gas emissions
E15	Photochemical oxidant formation
O1	Inappropriate labour cost
O2	Lack of raw material
O3	Lack of skilled labourers
O4	Lack of automation
O5	Lack of profitability / income generation
O6	Improper consumption pattern
O7	Lack of capital availability and usage
O8	Lack of equipment renovation & recyclability
O9	Inadequacy of training and competence
O10	Lack of emergency preparedness and response
O11	Inadequate grievance mechanism
O12	Lack of transparency in dissemination / data
O13	Lack of innovation
O14	Improper working conditions
O15	Unfair wages
S1	Work stress of employees and their shift work
S2	Unemployment
S3	Displacement of people
S4	Sustainable regional social protection system
S5	Lack of occupational health and safety practices
S6	Labour and management relations
S7	Lack of diversity and equal opportunity
S8	Poverty of local community
S9	Lack of work/life balance
S10	Lack of freedom for human rights
S11	Gender equity
S12	Lack of involvement of local community
S13	Lack of social inclusion in mining industry
S14	Lack of cultural diversity
S15	Involvement of child labour
(D + R)	Sum of row and column of the challenges (Prominence of the challenges)
(D-R)	Difference between row and column of the challenges (Influence of the challenges)

role as a major economic contributor, India's mining industries also serve as a catalyst for the growth of other industries such as power, steel, and cement. While the mining industries do play a significant role in support of the economy, the mining industries' adverse environmental impact during the processing stage is irreparable and remains a major concern (Kinnunen and Kaksonen, 2019). As there is no proper monitoring and regulating committee, the mining industries explore the resources in an uncontrolled manner. As a result, India ranks 177 amongst 180 countries in terms of the environmental performance index (https://epi.yale.edu/epi-results/2020/component/epi). Only after the Brundtland Committee report (1987) has the concept of sustainability gained importance amongst the industrial community. Although sustainability in routine industrial activities has become essential, the industrial community faces difficulties in the transition towards sustainable practices (Alves et al., 2020). Sustainable development is an industrial progress in which industry may use natural resources at a rate they can be replenished naturally. When the definition of sustainable development is considered, mining industries worldwide, especially in India, have failed to adhere to it. India's natural resources are depleted quickly by industrial sectors and disappear at a pace that cannot be reliably replenished (Ranjan, 2019). Hence, India's mining industries are in a situation to accept and adopt a sustainable development process. By incorporating sustainable manufacturing practices in the industrial activity, the industrial community may witness a progressive leap towards sustainable development goals (Sandberg et al., 2020).

As the problems related to the mining industry has been a major concern for global nations, several research works are being carried out. Most of the research works highlight the lack of institutional governance and the absence of pressure from the community as the major reason for the burgeoning environmental problems (Chand et al., 2020). The government's role is crucial in safeguarding natural resources by meeting the present need without affecting future needs (Ortiz-Barrios et al., 2020). In such a case, sustainable practice is vital in the mining industry as it is a non-renewable resource (Pezeshkan and Navid, 2020). Herrera-León et al. (2019) study in Chile's mining industries revealed that the uncontrolled extraction of minerals as the main factor for the increasing loss of biodiversity and the increasing level of pollution. Another study by Nasih et al. (2019) examining the Indonesian mining industry's impact emphasised that the carbon emission from the mining industry is higher than other industrial sectors in Indonesia. Failure of stringent law towards environmental conservation gives way to lobbyists, which hamper the law's enforcement (Hobbs, 2020).

From the above observations, it is clear that the mining industrial activities need to be monitored and the progress of mining industries towards sustainability needs to be accessed. Also, it is evident that with stringent law and sustainability awareness, the developed nations have mitigated the mining industry's adverse impact (Alves et al., 2020). However, the scenario is different in developing countries. India's mining industry needs adequate technological support, strict environmental regulations, and financial support. Further, the road to sustainability needs more cautious steps like awareness programs, technical support, and financial assistance (Iqbal et al., 2020). It is well known that the need for sustainable practice is common for both developing and developed countries; however, developing countries like India need more attention. A study on the challenges in moving towards sustainability in the mining industry context is a topic underdeveloped in the literature (Singh et al., 2020).

By considering the above information, this work aims to identify the most important challenges faced by the mining industry under each category (environmental, operational, and social) and suggest possible solutions. Also, this study aims to understand the interrelationship between the challenges faced by the Indian mining industry. The reason for carrying the study in the Indian context is that India is a developing country and its growth is predicted to be exponential in the coming years (Sandberg et al., 2020; Pandey et al., 2020). Also, a study by considering India as a case country will act as a reference for the mining industry located

in other developing countries where the socio-economic situation is similar. In this context, this study is significant. This research raises some questions for analysis as follows:

1. What are the challenges that need to be considered for implementing sustainable practices in Indian mining industry?
2. How should the potential challenges in the implementation of sustainable practices be prioritized?
3. How should interrelationships be established amongst the identified challenges for a successful implementation of sustainable practices?

The study aims to reveal the interrelationships amongst different challenges in implementing sustainable practices using the multi-criteria decision-making (MCDM) technique. For this, the study utilized Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology in the fuzzy context. Fuzzy DEMATEL technique is used in this work over other MCDM techniques as it reveals the interrelationships and prominence of one challenge over other challenges. Also, fuzzy DEMATEL categorizes the challenges under the binary categories of cause and effect. Such findings will highlight the challenges that needs imminent attention. The findings of fuzzy DEMATEL may assist industrial managers and practitioners in framing strategies to implement sustainable practice successfully.

The remainder of the paper is as follows: Section 2 summarizes the various challenges to implementing sustainable practices. The methodology used for the study is explained in Section 3. In Section 4, the applicability of the proposed methodology in a real case environment is explained. Section 5 explores the significant findings of the study. Managerial suggestions are provided in Section 6. Finally, Section 7 concludes the study with contributions, limitations, and scope for future study.

2. Literature review

Challenges in sustainability practice were identified by performing a Systematic Literature Review (SLR). For this, we searched research articles published in leading databases (Scopus, Google Scholar, and Web of Science) using keywords 'Sustainability in the mining industry', 'Barriers in sustainability practices', and 'Challenges in sustainability practice'. Also, Boolean operators such as 'challenges in environmental sustainability' OR 'barriers to environmental sustainability', 'inhibitors to sustainability' AND 'obstacle in sustainability', 'problem in adopting sustainability' AND 'impedance in adopting sustainability', 'problems faced by the mining industry in sustainability' OR 'challenges faced by the mining industry in sustainability' were used. Initially, 130 articles related to sustainability issues were identified, some of which were found to be duplicates. After rejecting duplicated works, we finalized 80 articles for a literature review. From an analysis of these 80 articles, we identified 45 challenges related to sustainability practices that we classified into three categories aligned with the triple bottom line (TBL) concept. 15 challenges are classified as **environmental**, 15 are in the **operational** category, and 15 fall under **social** concerns. The identified challenges in each category are discussed as follows:

2.1. Environmental challenges involved in the mining industry

Mining industries extract valuable minerals from the earth, so they wholly depend on nature. These natural resources are exploited in an unchecked manner (Caron and Asselin, 2020), resulting in ecological disturbance, loss of biodiversity, and loss of local flora and fauna. Ecological disturbance can be seen in soil erosion, deforestation, and land sliding (Das and Choudhury, 2013). The adverse environmental impact created by the mining industry is common in both developing and developed industry. The role of mining industry in boosting the country's economy is significant. Hence, it is not possible to completely ban mining activities (Komljenovic et al., 2015). However, it is possible for the mining industries to regulate, monitor, and control the exploration of natural resources. Famiyeh et al. (2020) insist that the adoption of sustainability in industrial activities provides a company with a market edge over its competitors. However, the study also highlights that the various challenges which fall under environmental, operational, and social categories may hamper sustainability progress. Measuring the rate of exploration and adoption of the trade scheme has been suggested as an efficient method to rectify the mining industry's environmental and human issues (Watson and Beharrell, 2006). Hilson (2000) examined issues related to the mining industry and identified economical, technological, and legislative issues as the barriers in the implementation of cleaner production methods. The findings of the study suggest that by improving labour training and education, enacting changes in internal operations, and adopting strict rules from government will lower pollution levels. Although a lot of technological options are available that deal with the minimization of water, air, noise, and land pollution, most of them cannot be adapted to the mining industry since they pertain to small-scale industries (Jenkins and Yakovleva, 2006; Hilson and Monhemius, 2006). Anawar et al. (2015) reviewed the functional properties of biochar and its impact level to reduce acid production during acid mine drainage treatments; they also sought solutions for soil contamination problems in the mining industry and sewage wastes. O'Regan and Moles (2006) described a graphical and mathematical model of the interactions between environmental and economic challenges in the mining industry using system dynamics. Some of the criticism related to the environmental aspects of sustainability concepts are given in Table 1.

2.2. Operational challenges involved in the mining industry

Sutomo (2020) reviewed various literature from 1974 to 2019 to identify challenges influencing mining operations. Around 200 challenges, namely those needed to improve operations, marketing, resource utility, corporate social responsibility (CSR), environment, human resources, and finance were indicated as severe challenges. Govindan et al. (2014) investigated drivers for CSR implementation in the mining industry and highlighted financial assistance as the major limitation in the CSR activity of the industries. Nearly 26 sub-drivers, such as avoidance of child labour, unemployment, sustainable support, conservation of the environment, minimization of emissions, and government regulations, were indicated as the major challenge in CSR activity. Lööw and Nygren (2019) developed a human and machine labour distribution model at intellectual production in Industry 4.0. Regression analysis was used for analysing the independent and dependant variables. Sishi and Telukdarie (2020) emphasised the incorporation of Industry 4.0 technologies for efficient business management. Pactwa et al. (2020) analysed coal mining waste management problems in Poland; their outcome suggests applying advanced technology for effective adoption of the 3R principles (Reduction, Reuse, and Recycle) will assist the mining industry to move towards practices endorsed by the circular economy. A study by Nikulin et al. (2019) on managing mine fires in Australian coal mining industry context revealed the failure to incorporate the latest technology as the main reason. Another study by Carstens and Hilson (2009) that considered coal mines in Tanzania revealed industrial managements take advantage of poverty conditions by harnessing the workers in coal mines. This same study also determined that the grievances of Tanzanian coal mine workers were not addressed. Warhurst and Bridge (1996) analysed the mining

Table 1
Environmental challenges to the mining industry.

S. No	Environmental challenges	Explanation	References
1	Failure of mining roof from the extraction of resources (E1)	Mineral extraction from the earth's crust affects the mining roof and affects the surrounding environment	Das and Choudhury (2013); Jenkins and Yakovleva (2006); O'Regan and Moles (2006);Watson and Beharrell (2006)
2	Contamination of air, soil, and water (E2)	Direct disposal of mining waste contaminates air, water, and soil	Anawar et al. (2015); Hilson (2000); Sarupria et al. (2019)
3	Pollution to the environment from the chemicals used in extraction process (E3)	Untreated chemical wastes entering the environment causes pollution	Hilson and Monhemius (2006)
4	Poor waste management process (E4)	Failure of industrial management in handling the generated wastes	Das and Choudhury (2013); Hilson (2000); Hilson and Murck (2000)
5	Environmental regulations (E5)	Non-existence of stringent environmental law fails to check uncontrolled pollution	Govindan et al. (2014); Hilson and Nayee (2002); Jenkins and Yakovleva (2006); Söderholm et al. (2015)
6	Non-adherence to green policy (E6)	Being unaware of the significance of sustainable manufacturing, the mining industries are not following green policy	Govindan et al. (2014); Gruenhagen and Parker (2020); Hilson and Murck (2000)
7	Potential effect on buildings, built structures due to climate change (E7)	Emitting gases like CO_2 from mining processes and cutting trees contributes to climate change	Pellegrino and Lodhia (2012)
8	Sinkholes formed by the method employed for mining (E8)	Use of outdated method leads to the formation of sinkholes	Hull et al. (1996)
9	Energy consumption (E9)	Traditional mining methods consume an enormous amount of energy that leads to wasteful and inefficient operations	Govindan et al. (2014); Norgate and Haque (2010); Jeswiet and Szekeres (2016)
10	Water depletion (E10)	The entry of industrial mining wastes directly into water bodies causes water contamination	Hilson and Murck (2000); Sarupria et al. (2019)
11	Mineral source depletion (E11)	Uncontrolled exploration of the mineral resources from the earth's crust leads to a shortage	Hilson and Murck (2000); Prior et al. (2012)
12	Fossil fuel depletion (E12)	Overdependence on fossil fuel leads to a shortage	Carvalho, (2007)
13	Particulate matter formation by mineral dust (coarse particles) and engine emissions (fine particles) (E13)	Waste from the mining industry deposits on the water bodies by forming a layer	Ishtiaq et al. (2018); Hilson and Nayee (2002)
14	Greenhouse gas emissions (E14)	Waste from the mining industry emits hazardous greenhouse gases	Norgate and Haque (2010)
15	Photochemical oxidant formation (E15)	Nitrogen wastes from the mining industry result in photochemical oxidant formation	Dunmade et al. (2019)

industry's recent trends to improve environmental performance through innovative ideas. The ability to improve competitiveness and environmental performance is strongly influenced by a company's capacity to effect and sustain technological and organizational change in response to changing regulatory and market pressures. Lööw et al. (2019) assessed the impact of technological innovation in the mining industry and highlighted that technological incorporation will benefit the mining industry in several various activities, from the collection of raw material to processing. Various challenges related to operational issues in the sustainability concept are given in Table 2.

2.3. Social challenges involved in the mining industry

Shrivastava and Vidhi (2020) reviewed sustainability strategies and initiatives for improving environmental, social, and economic responsibilities in the mining industry. As a result of the initiatives, they found that reduced emissions and waste, improved working conditions for the workers, improved recycling rates, good utilization of renewable energy, and protection of human rights will help improve sustainable development in the mining industry. Vivoda and Kemp (2019) concluded that the mining industries are not interested in attaining sustainable development goals. Without the intention of achieving sustainable development goals, it is difficult for the mining industries to incorporate sustainability in regular industrial activities. This was supported by the study of Moomen et al. (2019) which revealed that the mining industries are devoid of technological adoption which hampers their achievement of Sustainable Development Goals 2030. Shannon and Parker (2020) reviewed the mental health of the workers in the mining industry through an intervention study, and their findings underlined the need to establish a strong rapport between individual workers and the organization. Jiskani et al. (2020) evaluated the role of cognitive factors in workplace accidents by pursuing case studies in the coal mining industry. Their study found truck drivers most often breached the industry's safety rules and, hence, was the primary cause for workplace accidents. Zhang et al. (2020) analysed the root causes for coal mine accidents and found the fundamental reasons for accidents were ignoring the safety laws and regulations, lacking attention to the safety education for the mining workers and supervisors, ignoring safety as a priority, and limiting the role of functional departments. Asr et al. (2019) proposed a systematic framework for transforming the mining industry from a conventional manner to sustainable manufacturing practices based on the result of case study findings Jacobs et al. (2008) investigated the interaction between the mining workers' employment and their personal lives in the Northern Cape mining industry by interacting with 25 mine workers. From the interaction, it was found that several challenges, including heavy workload, stress, and work pressure led to specific consequences such as a lack of quality time spent with their family, emotional strain, low productivity, personal stress, and so forth. Aron and Molina (2020) discussed the regulatory gaps in security regulations and classified procedure decisions intended to develop the Canadian mining industry's lack of responsibility. In some conditions, the establishment of a mining industry forces the displacement of local residents (Owen et al., 2020). Table 3 lists the challenges that are related to the social aspect of the sustainability concept.

3. Research methodology

The framework of the proposed study is displayed in Fig. 1. The proposed research work consists of two stages. In the first stage, the challenges related to sustainability practice are finalized using

Table 2
Operational challenges to mining industry.

S. No	Operational challenges	Explanation	References
1	Inappropriate labour cost (O1)	Although labourers in the mining industry are harnessed, they are not paid an appropriate salary	Gruenhagen and Parker (2020)
2	Lack of raw material (O2)	Uncontrolled exploitation of natural resources has led to scarce raw material	Gruenhagen and Parker (2020)
3	Lack of skilled labourers (O3)	The absence of skilled labourers hampers industrial progress towards a sustainable manufacturing process	Gruenhagen and Parker (2020)
4	Lack of automation (O4)	With financial shortages, the industries are unable to automate	Govindan et al. (2014)
5	Lack of profitability/income generation (O5)	With the increase in business competition, income generation has become difficult	Govindan et al. (2014); Gruenhagen and Parker (2020); Sutomo (2020); Sarupria et al. (2019)
6	Improper consumption pattern (O6)	Following traditional methods and poor planning leads to improper consumption patterns	Mudd (2010)
7	Lack of capital availability and usage (O7)	The failure of industrial management implies a lack of capital investment and its usage	Bijańska and Wodarski (2020); Lööw and Nygren (2019)
8	Lack of equipment renovation & recyclability (O8)	Being financially weak, the mining industries are unable to renovate the machinery	Pactwa et al. (2020); Vostrikov et al. (2019); Sishi and Telukdarie (2020)
9	Inadequacy of training and competence (O9)	As the labourers are semi-skilled, they do not possess a sufficient degree of competence	Zhang (2017); Roldán et al. (2019)
10	Lack of emergency preparedness and response (O10)	Unawareness of safety norms is the cause for non-preparedness in the case of emergencies	Nikulin et al. (2019); Zvarivadza (2018)
11	Inadequate grievance mechanism (O11)	Non-adherence to worker's safety norms is the reason for inadequate grievance mechanisms	Carstens and Hilson (2009)
12	Lack of transparency in dissemination / data (O12)	With no standard framework in practice, mining industries are not maintaining data on work-related accidents and other related issues	Abudu and Sai (2020)
13	Lack of innovation (O13)	Being an SME, the mining industries are not able to enhance the R&D section	Gruenhagen and Parker (2020); Lööw et al. (2019); Warhurst and Bridge (1996)
14	Improper working conditions (O14)	The incapability of mining industries to provide an ambient working environment is a challenge	Brereton and Parmenter (2008); Tuokuu et al. (2019)
15	Unfair wages (O15)	Regardless of the work involved, gender bias is present in the wages of employees	Thasi and van der Walt (2020)

Table 3
Social challenges to mining industry.

S. No	Social challenges	Explanation	References
1	Work stress of employees and their shift work (S1)	As there is no scheduled work time and poor work policy in most mining industries, the workers are exposed to stress	Shrivastava and Vidhi (2020)
2	Unemployment (S2)	Lack of raw material supplies and technological changes implies unemployment in the mining sector	Shrivastava and Vidhi (2020)
3	Displacement of people (S3)	The establishment of the mining industry forces the people of the local community to migrate	Jiskani et al. (2020); Zhang et al. (2020)
4	Sustainable regional social protection system (S4)	Failure to provide reasonable protection system for the workers to protect their health and mental ability	Shannon and Parker (2020); Frederiksen (2018); Asr et al. (2019); Harris et al. (2021)
5	Lack of occupational health and safety practices (S5)	Insufficient commitment from top management results in a lack of safety practices	Gruenhagen and Parker (2020)
6	Labour and management relations (S6)	The poor relationship between labour and management leads to misunderstanding	Frederiksen (2018); Jones et al. (2007)
7	Lack of diversity and equal opportunity (S7)	Failure in fair management practice is the reason for unequal opportunities	Bryant and Tedmanson (2005)
8	Poverty of local community (S8)	Ineffective wage practice aggregates poverty	Deaton and Niman (2012); Pegg (2006)
9	Lack of work/life balance (S9)	Continuous work schedule without sufficient interval cause work imbalance	Jacobs et al. (2008); Munawer (2018)
10	Lack of freedom for human rights (S10)	Workers in mining industries are denied their fundamental rights	Aron and Molina (2020); Sullivan and Frankental (2002)
11	Gender equity (S11)	Ignoring female workers, mining industries are mostly preferring male workers	Bogusz and Sulich (2020); Bryant and Tedmanson (2005); Kaggwa (2020); Salinas et al. (2018)
12	Lack of involvement of local community (S12)	Failure to maintain the right healthy environment and social life leads to a lack of local community involvement in their work	Jenkins (2004)
13	Lack of social inclusion in mining industry (S13)	Lack of opportunities and dignity causes a failure in the social inclusion of workers in the mining industry	Frederiksen (2018); Romano and Papastefanaki (2020)
14	Lack of cultural diversity (S14)	Failure to motivate, recognize, respect, and acknowledge differences leads to a loss in cultural diversity	Govindan et al. (2014)
15	Involvement of child labour (S15)	Poverty has increased the practice of child labour.	Hilson (2010)

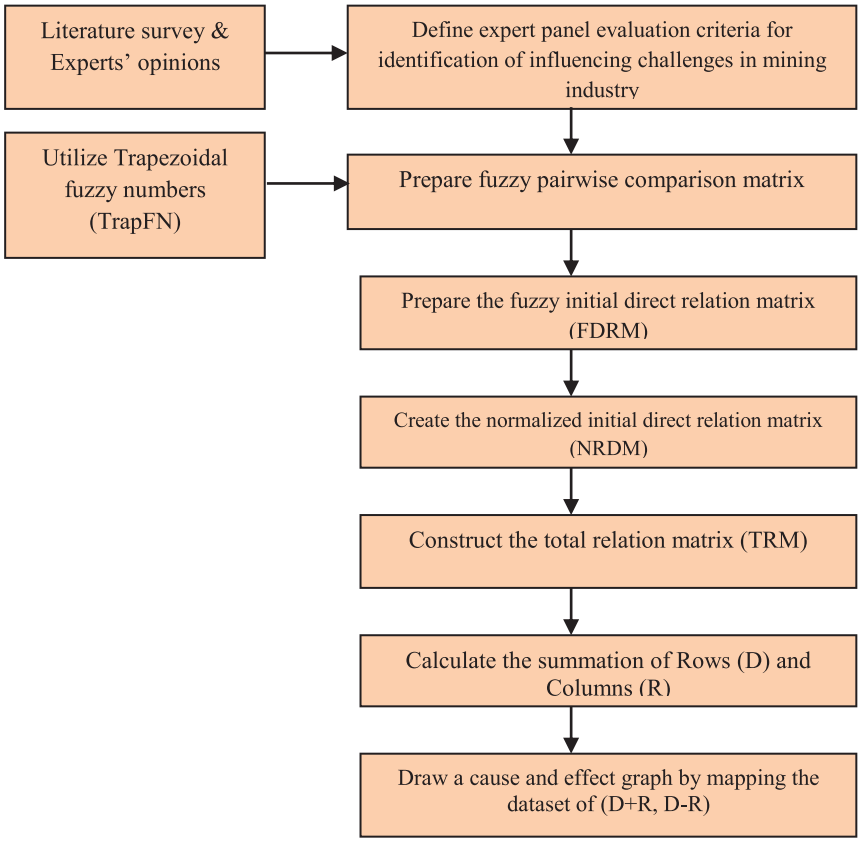

Fig. 1. Framework of the proposed study.

expert opinions. In the second stage, the weight and interrelationships amongst the challenges are revealed using fuzzy DEMATEL.

- Stage 1: Finalization of challenges

To validate the appropriateness of the identified challenges, we sought the opinions of the experts. For this, a questionnaire (Appendix A, Table A2) consisting of the identified 45 challenges was given to an expert panel comprised of eight members who have substantial knowledge of sustainable practices (Appendix A, Table A3). The reliability of the questionnaire is tested by calculating Cronbach's α. Generally, Cronbach's α value of above 0.70 is accepted. Cronbach's α value of the questionnaire used in this study is 0.808, well above the acceptable value. Hence, the questionnaire is reliable. Further, to analyse the questionnaire's validity, Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity are calculated. KMO equal to or greater than 0.5, and with significant values less than 0.05, means the data are eligible for further analysis. In our case, the KMO value is 0.758, and the significance value is 0. Hence, the questionnaire containing the challenges is eligible for further analysis. The given questionnaire is a YES/NO type; it also requests the experts to express their opinions. If the expert agrees with the listed challenge, the expert must answer YES and, if they do not agree, NO. The experts were asked to finalize the challenges and could edit or suggest any modification they deemed important. Frequent reminders were given to the experts to secure their opinion. Based on the experts' suggestion, we found they were satisfied with the selected 45 challenges.

- Stage 2: Fuzzy-DEMATEL approach

The decision-making trial and evaluation laboratory (DEMATEL) method by Gabus and Fontela (1972) is most appropriate for analysing complex causal relationships amongst challenges (Karuppiah et al., 2020a). DEMATEL is a structural modelling approach that can represent the interdependence of various challenges and their cause-effect relationships in the form of a digraph. In the DEMATEL method, all the challenges (in this study, multiple challenges related to the mining industry) are divided into cause and effect groups to help identify their causal relationships. The procedure for Fuzzy DEMATEL methodology is explained as follows:

Step 1. *Collecting experts' opinion and categorising evaluation criteria*

A panel consisting of industry experts is formed and valuable suggestions on related subjects are obtained. These industrial experts have vast experience in the mining field for problem-solving. The key challenges affecting the mining industry were collected from the existing literature, and industrial experts' opinions on the identified challenges were obtained.

Step 2. *Preparing a Fuzzy Direct Assessment Matrix*

Once the key challenges are identified, pairwise comparison for challenges must be carried out. For this, a fuzzy linguistic scale with five different points (0=no influence, 1=very low influence, 2=low influence, 3=high influence, 4=very high influence) is used to assist experts in assessing the interrelations amongst various challenges. Experts are requested to allocate ratings based on the fuzzy linguistic scale to develop an assessment matrix as part of the assessment criteria. When assessing and modifying linguistic content from experts, predictions go into fuzzy evaluations, leading to an optimistic TrapFN presented in Table A1. TrapFN is represented by a quadruplet, i.e., ($x1_{ij}$, $y1_{ij}$, $z1_{ij}$, $w1_{ij}$), where $x1 \leq y1 \leq z1 \leq w1$. Let $A1\frac{k}{ij} = (x1\frac{k}{ij}, y1\frac{k}{ij}, z1\frac{k}{ij}, w1\frac{k}{ij})$, where $1 \leq k \leq k$, $1 \leq i \leq n$; $1 \leq j \leq n$ is the fuzzy classification that the kth decision maker provides for rating if factor i affects factor j.

Step 3. *Create a Fuzzy Initial Direct Relation Matrix (FDRM)*

Defuzzification is the process of changing fuzzy numbers to corresponding crisp values. FDRM is obtained using Eq. (1).

Average k obtained from n x n FDRM is computed for all decision makers, where k is the number of decision makers:

$$I_t = \frac{1}{4}(x1 + y1 + z1 + w1) \tag{1}$$

Step 4. *Prepare the normalized, initial, direct relation matrix (NDRM) using Eqs. (2) and (3)*

$$m = \min\left[\frac{1}{\max\sum_{i=1}^{n}|aij|}, \frac{1}{\max\sum_{j=1}^{n}|aij|}\right] \tag{2}$$

$$NDRM = mA \tag{3}$$

Step 5. *Construct the Total Relation Matrix (TRM) using Eq. (4) as follows:*

$$TRM = (I - NDRM)^{-1} \tag{4}$$

Where $_{I=}$ identity matrix and$TRM = [t_{ij}]_{nxm}$.

i and j represent the criteria in the pairwise comparison matrix.

Step 6. *Compute the summation of rows (D) and columns (R) by using Eqs. (5) and 6 as follows.*

$$D = \left\{\sum_{j=1}^{n} t_{ij}\right\}_{nx1} \tag{5}$$

$$R\left\{\sum_{i=1}^{n} t_{ij}\right\}_{1xn} \tag{6}$$

D represents the impact of criterion i on criterion j and R represents the impact of criterion j on criterion i.

Step 7. *Draw Cause and Effect graph by mapping the dataset of (D + R, D-R).*

The sum $(D+R)$ denotes the importance of key challenges called 'Prominence' in the mining industry. On the other hand, (D-R) denotes the 'Influence' in the mining industry. If a positive value is acquired from (D-R), the challenge is categorised in cause group and if a negative value is acquired from (D-R), then the challenge is categorised in effect group. Fig. 1 represents the flowchart of steps involved in Fuzzy DEMATEL method.

4. Application of the proposed methodology

The proposed framework for analysing the challenges to the successful implementation of sustainable practice is applied in the mining industry. First, the challenges are identified using literature review, and based on experts' opinions, the identified challenges were categorised under social, environmental, and operational categories, each consisting of 15 challenges. A questionnaire consisting of the identified challenges was given to the experts for the case study. Based on the response of experts, using fuzzy-DEMATEL, the challenges are evaluated.

The reason for selecting the mining industry in India is that it has a direct adverse impact on both the environment and on its workers. Such an undesired impact on the environment and workers has degraded the mining industry's reputation. As a result, the mining industry has been considered one of the prime polluters in India. Brief details about the selected mining industry are given in (Appendix A, Table A1).

The application of the proposed methodology is given below:

Step 1. Pairwise comparison matrix is formulated using the fuzzy linguistic scale shown in Appendix A, Table A4. The fuzzy assessment matrix for main challenges is given in Appendix B, Table B1, B2, B3.

Step 2. Create initial direct relation matrix (FDRM) with the usage of converting the fuzzy numbers into crisp values by defuzzification, as mentioned in step 3 of Fuzzy DEMATEL approach. FDRM for key challenges of the mining industry is given in Appendix B, Table B4, B5, B6.

Step 3. Next, the Normalized direct relation matrix (NDRM) is computed using Eqs. (3) and (4). Fuzzy NDRM of key mining industry challenges for environmental, operational, and social challenges are given in Appendix B, Table B7, B8, B9.

Step 4. Total relation matrix (TRM) is calculated using Eq. (5). Fuzzy TRM of key mining industry challenges for environmental, operational, and social challenges are given in Appendix B, Table B10, B11, and B12.

Step 5. Next, Sum of Rows (D) and Columns (R) are obtained using Eqs. (6) and (7) and given in Tables 4, 5, and 6.

Next, the positioning of challenges in the mining industry is made derived from data sets $(D+R)$ and (D-R). The challenges are categorised into the cause or effect group from the data sets $(D+R)$ and (D-R) values arrived (Table 4, 5, and 6). Next, a causal

Table 4
Calculation of $(D+R)$ and (D-R) data sets for environmental challenges in the mining industry.

Challenges	D	R	$D+R$	Rank	D-R	Cause/Effect
E1	4.464	3.788	8.252	7	0.676	Cause
E2	4.175	4.154	8.329	5	0.022	Cause
E3	3.761	3.917	7.678	8	−0.156	Effect
E4	4.495	3.781	8.276	6	0.713	Cause
E5	4.400	4.419	8.819	2	−0.019	Effect
E6	4.703	3.784	8.487	3	0.920	Cause
E7	4.327	4.787	9.114	1	−0.459	Effect
E8	4.608	3.868	8.475	4	0.740	Cause
E9	4.171	3.471	7.642	9	0.699	Cause
E10	3.289	3.324	6.613	13	−0.035	Effect
E11	2.983	3.155	6.138	15	−0.173	Effect
E12	3.161	3.439	6.600	14	−0.278	Effect
E13	3.207	4.070	7.278	11	−0.863	Effect
E14	3.219	4.270	7.489	10	−1.051	Effect
E15	3.198	3.935	7.134	12	−0.737	Effect

Table 5
Calculation of $(D+R)$ and (D-R) data sets for operational challenges in the mining industry.

Challenges	D	R	$D+R$	Rank	D-R	Cause/Effect
O1	4.344	3.921	8.265	7	0.423	Cause
O2	3.480	2.646	6.126	15	0.834	Cause
O3	4.595	3.791	8.386	5	0.804	Cause
O4	3.844	4.540	8.384	6	−0.696	Effect
O5	3.795	4.940	8.735	2	−1.145	Effect
O6	4.170	3.634	7.804	11	0.535	Cause
O7	4.546	3.288	7.833	10	1.258	Cause
O8	3.651	3.776	7.427	13	−0.125	Effect
O9	4.087	3.975	8.062	9	0.111	Cause
O10	4.460	4.112	8.572	4	0.348	Cause
O11	3.832	4.262	8.095	8	−0.430	Effect
O12	3.187	3.989	7.176	14	−0.802	Effect
O13	4.656	4.950	9.606	1	−0.294	Effect
O14	4.042	4.539	8.580	3	−0.497	Effect
O15	3.677	4.001	7.679	12	−0.324	Effect

Table 6
Calculation of $(D+R)$ and (D-R) data sets for social challenges in the mining industry.

Challenges	D	R	$D+R$	Rank	D-R	Cause/Effect
S1	3.661	2.256	5.917	10	1.405	Cause
S2	3.027	2.467	5.494	13	0.560	Cause
S3	2.969	2.369	5.338	15	0.600	Cause
S4	3.502	2.624	6.126	9	0.879	Cause
S5	3.235	2.563	5.798	11	0.673	Cause
S6	4.005	4.170	8.175	1	−0.165	Effect
S7	3.109	3.161	6.271	8	−0.052	Effect
S8	2.779	3.727	6.506	7	−0.949	Effect
S9	2.770	2.683	5.453	14	0.087	Cause
S10	4.000	4.046	8.046	2	−0.046	Effect
S11	3.231	3.658	6.890	5	−0.427	Effect
S12	3.102	3.707	6.809	6	−0.606	Effect
S13	3.173	3.779	6.952	3	−0.606	Effect
S14	3.109	3.803	6.913	4	−0.694	Effect
S15	2.463	3.121	5.584	12	−0.658	Effect

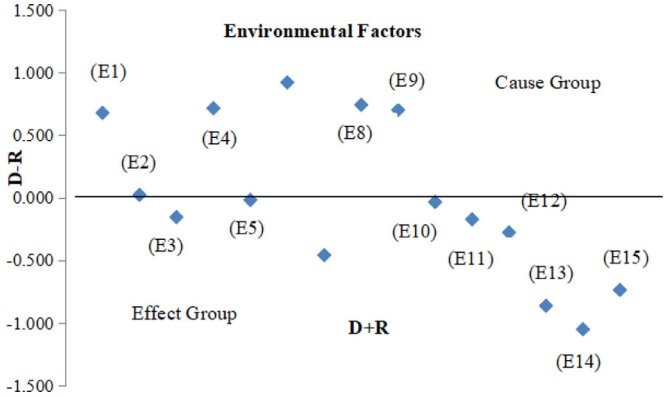

Fig. 2. Cause and effect group for environmental challenges.

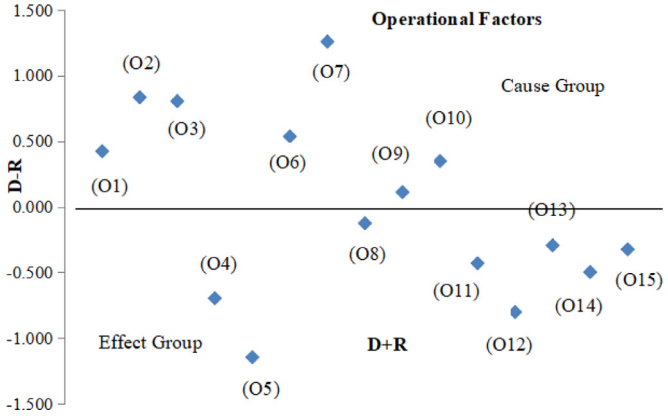

Fig. 3. Cause and effect group for operational challenges.

diagram is drawn from the data sets values, which is shown in Fig. 2, 3, and 4.

The data set value $(D+R)$ represents the 'Prominence' level of the challenges. The data set (D-R) categorises the challenges under cause and effect group. Using data set (D-R), the casual diagram for the challenges is drawn and from the casual diagram, the policy makers and industrial practitioners may become aware of the areas that need to be strengthened.

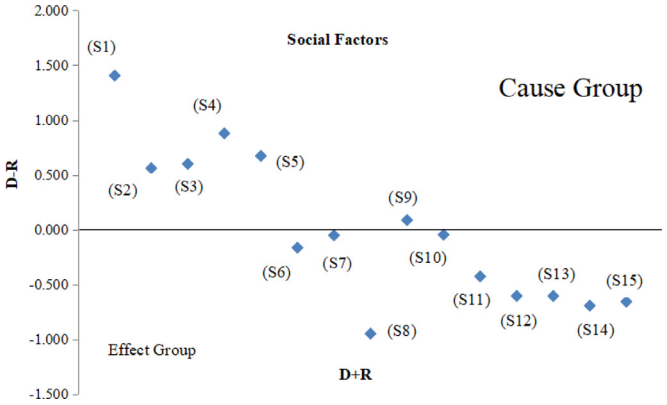

Fig. 4. Cause and effect group for social challenges.

5. Results and discussion

In this section, the results obtained from analysing the 45 challenges affecting environmental, operational, and social areas of concern in the mining industry is discussed using Fuzzy DEMATEL. Figs. 2, 3, and 4 show the cause and effect group attained as the outcome of the work. Next, we discuss the prominence challenges followed by influencing and resulting challenges.

5.1. Prominence challenges

The order of prominence of the 15 significant challenges related to the environmental category in the mining industry through a level of significance $(D+R)$ is noted as E7>E5>E6>E8>E2>E4>E1>E3>E9>E14>E13>E15>E10>E12>E11. Climate change (E7), Environmental regulations (E5), and Non-adherence to green policy (E6) are the most significant challenges compared with other environmental challenges in that category with the values of 9.114, 8.819, and 8.487, respectively. On the other end, mineral source depletion (E11), fossil fuel depletion (E12), and water depletion (E10) are the least significant challenges compared with other environmental challenges with the values of 6.138, 6.600, and 6.613. The finding of Climate change (E7) as the prominent challenge was acceptable as any degradation of the natural resource will alter the climatic pattern. Kinnunen and Kaksonen (2019) supported this finding, which states that valorisation in the mining industry brings an adverse change in the environment. Uncontrolled exploration of natural resources has been reported as the main reason for adverse environmental impact (Qarnain et al., 2020). Consuming natural resources in a measured manner for the use of the present generation by considering the future generation will reduce the uncontrolled consumption of natural resources (Bathrinath et al., 2019). The framed Environmental Regulations (E5) must be strictly applied for this reason. Many developing countries like India have failed to enforce strict environmental regulations. As a result, the mining industries do not comply with environmental regulations. Many mining industries fail to adhere to the green policy. The fine imposed for non-adherence of the industry to green policy is less in comparison with the cost required to adhere to green policy (Karuppiah et al., 2020a). Because of this inequity, the industries are not willing to adopt the green policy.

In the operational challenges category, the order of significance $(D+R)$ is rated as O13>O5>O14>O10>O3>O4>O1>O11>O9>O7>O6>O15>O8>O12>O2. Lack of innovation (O13), lack

of profitability/income generation (O5), and improper working conditions (O14) are the most significant challenges compared with other operational challenges in that category with the values of 9.606, 8.735, and 8.580, respectively. On the other end, lack of raw material availability (O2), lack of transparency in dissemination/data (O12), and lack of renovation & recyclability (O8) are the least significant challenges compared with other operational challenges with the values of 6.126, 7.176, and 7.427. Lack of innovation (O13) is the result of limited technological exposure and capability. As most of the mining industries in India are SMEs, these mining industries' technological capabilities are very low (Raborar and Recio, 2020). The reason for limited technology lies in the fact that technological advancement has not been distributed in all sections of industries. Mining industries with large scale investments can afford advanced technologies, whereas it is not affordable for small industries (Chabukdhara and Singh, 2016). Also, the working environment of the mining industry poses a severe threat to the workforce. As the mining industry's operating environment is subjective to natural calamities like landslides, oxygen shortage, a proper investigation must be made before deploying the workforce. Safety measures need to be given in the workplace. Provision of safety measures and proper pre-investigation may bring down the occurrence of fatal accidents and improve the mining industry's working environment (Bhalaji et al., 2020). Such a practice will enhance the worker's health.

In the social challenges category, the order of significance $(D+R)$ is rated is S6>S10>S13>S14>S11>S12>S8>S7>S4>S1>S5>S15>S2>S9>S3. Lack of labour and management relations (S6), lack of freedom for human rights (S10), and lack of social inclusion (S13) are the most significant challenges compared with other social challenges in that category with the values of 8.175, 8.046, and 6.952, respectively. On the other end, displacement of people (S3), lack of work-life balance (S9), and unemployment (S2) are the least significant challenges compared with the other social challenges with the values of 5.338, 5.453 and 5.494. In most of the mining industries, the majority of workers are semi-skilled who are ready to work for meagre wages. Taking advantage of the workforce's situation, the mining industries are harnessing the workforce to extract maximum work (Robinson et al., 2021). Besides harnessing the workforce, the mining industries do not provide equal wages (Bijańska and Wodarski, 2020). Also, there is no fixed work schedule for the workers of the mining industry. Developing a set work schedule may optimise the production capability of the workers. In some cases, the necessary required safety measures have not been provided to the mineworkers. Such a claim is a violation of human rights. Such practices raise vital questions about the social sustainability performance of the industry.

5.2. Influencing challenges

The cause group challenges were ranked based on (D-R) values and it is significant to centre other challenges on them. amongst all the cause challenges, Non-adherence to green policy (E6) (D-R) has the highest impact on the value of 0.920 in the environmental category. As a result of not following the green policy, the mining industry releases greenhouse gases, leading to global warming, climate change, and increasing the earth's temperature (Gruenhagen and Parker, 2020). By considering these enormous issues, non-adherence to green policy is considered the first challenge in the cause group. The mining industry must adopt new technologies and innovations to switch over from fossil fuel usage to renewable fuels and to reduce waste to control emissions levels. The second most dominant cause challenge in the (D-R) column is method employed for mining (E8) with a value of 0.740. The method followed in the mining industry creates air and water pollution (Sarupria et al., 2019). It affects the health of surrounding residents and it impacts the whole environment. This is the reason that method employed for mining is categorised as the second important causal challenge. Increasing the renewable resources utilization, better characterisation of the ore body during exploration, and adopting new technologies are some of the remedial steps that the mining industry can implement to reduce the severity level. The third most severe challenge in the cause group is the waste management process (E4) with values of 0.713 (D-R). A poor waste management process in the mining industry affects the health of the surrounding people (Dunmade et al., 2019). The mining industry must check the possibility of recovery, recycling, and reuse of wastes. Energy consumption (E9) is the fourth significant challenge in the cause group and features an (D-R) value of 0.699. While digging deeper for minerals, metals, and fuels, the mining industry consumes enormous amounts of energy to run their equipment and trucks. By consuming more energy, waste levels increase, and the cost spent on mining also increases. The mining industry needs to analyse its equipment and processes and find new innovative ideas for effective utilization to control energy consumption. The next two cause challenges are extracting materials (E1) and contamination of air, soil, and water (E2) with the (D-R) values of 0.676 and 0.022, respectively. In these two, extracting materials (E1) has high (D-R) value and impacts the mining industry. Extracting materials in the mining industry leads to problems with erosion, sedimentation, and groundwater pollution (Asr et al., 2019). New technologies should be adopted to smooth the extraction of materials to overcome these problems. Contamination of air, soil, and water may affect the surrounding residents' health. Implementing renewable resources, waste reduction, and effective methods can prevent air, soil, and water contamination. amongst all the cause challenges, lack of capital and usage (O7) has the highest impact score with the (D-R) value of 1.258 in the operational category. As highlighted by Chand et al. (2020), effective usage of capital is an essential component to achieve a higher profit for the industry, protect the environment, and increase safety features. The second most important causal challenge is lack of raw material availability (O2). It has a (D-R) value of 0.834. Due to the lack of raw materials available for ores, minerals, and mines, mining companies utilize more in-depth extraction processes, which lead to climate change, earthquakes, destruction of natural resources, more vibration level, and so on. It will affect the surrounding people as well as the surrounding environment. Lack of availability of skilled labourers (O3) is the third most influencing cause challenge with the (D-R) value of 0.804. The average age of skilled labour in the mining industry is around 45 years (Karuppiah et al., 2020b). Getting skilled labour is difficult for mining companies in today's marketplace. At the initial stage of mine development or the construction phase, labour requirements are always at peak level. When moving to the production phase, the labour requirement is slightly reduced. To rectify the skilled labour availability issue, the mining industry needs to provide training to the hired employees. Governments should focus and make a clear strategic commitment to provide training required for current and future needs.

One of the significant challenges to be addressed in the mining industry is the work stress of employees and their shift work (S1), which falls under social challenges. For industries in which more physical work is required, like the mining industry, gender partiality in workers' wages is often apparent (Zvarivadza, 2018). In mining industries, male workers are assigned massive work, whereas the female workers are assigned light work. Citing differences in

the nature of work, salary differences are apparent in the mining industry (Famiyeh et al., 2020). Similarly, lack of occupational health and safety (S5) is also a significant challenge in the mining industry that needs the utmost attention. In the mining industry, explosives and heavy equipment are used and, hence, proper warning signage must be provided (Gruenhagen and Parker, 2020). Further, an appropriate collection of safety practices must be provided to mitigate or eliminate work-related accidents. Fundamental safety aspects like helmets, safety jackets, and protective gear must be provided to the mining workers. In addition to this, a properly scheduled work plan is not followed in many mining industries. The absence of a scheduled work plan leads to irregular work patterns, forcing the workers to work without adequate rest intervals. Working without a break induces mental stress and work pressure (Lööw and Nygren, 2019), so a well-planned work schedule with sufficient break intervals must be prepared and followed in the mining industries.

5.3. Resulting challenges

Environmental challenges in the effect group are affected by different challenges. They do not affect the system directly. Their ratings are as follows: E5>E10>E3>E11>E12>E7>E15>E13>E14. These nine challenges are directly influenced by the six causal challenges to environmental practices in the mining industry. In this category, environmental regulations (E5) have least (D-R) score of −0.019, and it was near the causal group, which shows it was less influenced by causal challenges. Other effect challenges were water depletion (E10), chemicals used in the extraction process (E3), mineral source depletion (E11), fossil fuel depletion (E12), climate change (E7), photochemical oxidant formation (E15), particulate matter formation (E13), and greenhouse gas emissions (E14). Greenhouse gas emissions (E14) have the minimum (D-R) score of −1.051 and show high impact. The mining industry has to minimize the usage of fossil fuels to reduce greenhouse gas emissions. They adapt to renewable resources; increasing energy efficiency is a remedial measure to protect greenhouse gas emissions. Further, the challenge of climate change (E7) has the highest $(D+R)$ value of 9.114, which validates its importance. Extreme weather, food supply disruption, and increased wildfires are other effects of climate change caused by greenhouse gases. Planting more trees, conserving existing forests and grasslands, and arresting CO_2 can be applied to control climate change. Following government regulations and practicing standards without violating important remedial solutions help to control greenhouse gas emissions and reduce climate change problems (Ishtiaq et al., 2018).

Operational challenges in the effect group are affected by different challenges. They do not modify the system directly. Their ratings are as follows: O8>O13>O15>O11>O14>O4>O12>O5. These eight challenges are directly influenced by the seven causal challenges to operational practices in the mining industry. In this category, lack of renovation and recyclability (O8) has the least (D-R) score of −0.125, which shows it is less influenced by causal challenges. Other effect challenges include lack of innovation (O13), fatigue and unfair wages (O15), grievance mechanism (O11), improper working conditions (O14), lack of automation (O4), transparency in dissemination/data (O12), and lack of profitability/income (O5). Lack of profitability/income (O5) has the minimum (D-R) score of −1.145 and shows a high impact. Increasing exploration and production costs have affected profit margins and leave shareholders restrained to keep with new projects, particularly with minor industries. New companies cannot compete with major companies and face the challenge of increasing the required capital to invest in expensive mining practices or high-cost machines/equipment. A flexible finance system will be a remedial solution and it permits smaller mining industries to maintain to drive the hurdles of exploration (Jiskani et al., 2020). In addition to this, the challenge lack of innovation (O13) has the highest $(D+R)$ value of 9.606 which shows the importance of impact level. Due to lack of innovation methodologies, the profitability level has dropped, and workers are satisfied with the mindset of existing work methods (Bhalaji et al., 2020). The organization is advised to initiate new innovative methods, procedures, policies, etc. to overcome this problem. Extra incentive schemes and bonus schemes are some of the remedial actions that could be taken to improve the workers' motivation levels.

Social challenges in the effect group are affected by different challenges; like the other categories, they do not affect the system directly. Their ratings are as follows: S10>S7>S6>S11>S12>S13>S15>S14>S8. These nine challenges are directly influenced by the six causal challenges to social practices in the mining industry. In this category, freedom for human rights (S10) and diversity and equal opportunity (S7) have the least score values of −0.046 and −0.052, respectively. These are near the causal group, which is less influenced by causal challenges. Other effect challenges are lack of labour and management relations (S6), lack of gender equity (S11), local community/public participation (S12), lack of social inclusion (S13), the involvement of child labour (S15), cultural sustainability (S14), and poverty (S8). In this effect group, the poverty level (S8) has a minimum (D-R) value of −0.949 and shows a high impact. The local public's poverty level creates an added advantage to the management indirectly for violating rules and standards (Abudu and Sai, 2020). Poverty is the main challenge that leads to creating many other problems. Lack of fair wages, conditions of work and social protection, and basic human rights problems are some of the problems created from the local people's poverty. In addition to this, lack of labour and management relations (S6) has the highest $(D+R)$ value of 8.175 and shows the importance level of impact. If the relationship between management and the labour side is not good, the entire working atmosphere will likely collapse. Work involvement levels amongst the workers get reduced and create unnecessary problems in the industry. The efficiency of the mining industry also drops significantly and leads to a reduction in profitability. Maintaining a smooth relationship between management and labour is one of the remedial solutions to rectify this problem (Nasih et al., 2019). This could be done by motivating worker's performance, rewarding the worker's innovative skill, flexible time working, increasing the safety features in the industry area, providing a comfortable working environment, awarding bonuses, offering frequent get-together meetings, and so on.

6. Conclusions

As a result of rapid industrialization, natural resources are getting exploited at a fast pace. Such exploitation leads to loss of biodiversity, soil erosion, and land sliding. The mining industry is one of the main sectors exploiting natural resources. As the sustainability concept is gaining importance, the mining industries need to incorporate sustainability practices into their regular industrial activity. However, in incorporating sustainability, the mining industries do face significant challenges. This paper evaluated a total of 45 challenges (15 in each of the three categories of environmental, operational, and social) faced by the mining industry in attaining sustainable practices using the fuzzy DEMATEL technique. The study's outcomes indicate climate change, lack of innovation, lack

of capital availability, lack of labour and management relations, and fair wages are the top challenges in the environmental, operational, and social issues, respectively, in India's mining industry. Based on the outcome, the study suggests some possible managerial implications for improving the mining industry's safety culture and moving towards sustainable manufacturing practice. The mining industry will benefit from adopting new technologies and innovations in the switch from fossil fuel usage to renewable fuels and reducing waste to control the mining industry's emission level (Söderholm et al., 2015; Dunmade et al., 2019). Effective and efficient capital usage is an essential objective to achieve a higher profit for the industry, protect the environment, and augment its safety features. As per the government's regulations, minimum fair wages should be provided to employees based on the skill level defined. Worker safety is a crucial challenge and should be considered first while applying the remedial measures for the issues identified in environmental, operational, and social categories.

This study has some limitations. For instance, the study is carried out in the Indian context only. However, the proposed methodological steps followed in this study can be applied to other developing country contexts. Following the proposed methodological steps, other studies in developing country contexts may validate the challenges reported in this study or discover new insights on the challenges based on the socio-economic and environmental conditions of the country of interest.

Another limitation to this the study is that it has not considered risk factors related to organization issues. Hence, in future studies, the risk factors related to organizations must be analysed. Also, in the future, other MCDM tools such as Fuzzy Cognitive Maps (FCM), Analytic Network Process (ANP), Analytic Hierarchy Process (AHP), Interpretive Structural modelling (ISM), and Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) could be used to evaluate the mining industry's most significant challenges. They may give good results to overcome the limitations mentioned.

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

A set of questionnaires was prepared to conduct surveys with the identified experts in three different mining industries to assess the challenges affecting environmental, operational, and social concerns in the mining industry. Experts are identified in different departments with high technical knowledge and vast experience in the mining industry. The profiles of the mining industry and the identified experts are provided in Table A1 and A2. The data collected from the survey was utilised for this research purpose only; it was not disclosed with any others. We requested that the experts select the ratings to assess the challenges as per the linguistic scale values given in Table A3.

Table A1
Description of the mining industry.

Business features	Mining Industry 1	Mining Industry 2	Mining Industry 3
Year of establishment	2000	2002	2008
Number of workers	150 – 200	100 – 125	120 – 150
Turnover (in INR) yearly	130 Crore	100 Crore	110 Crore

Table A2
Questionnaire used for getting experts' opinions
Please answer the following questions
a) Name: b) Role: C) Experience (in years):
Selection of critical challenges in sustainable mining: Please suggest your opinion on the challenges given below.

S. No	Challenges	Yes/No
1	Failure of mining roof from the extraction of resources (E1)	
2	Contamination of air, soil, and water (E2)	
3	Pollution to the environment from the chemicals used in extraction process (E3)	
4	Poor waste management process (E4)	
5	Environmental regulations (E5)	
6	Non-adherence to green policy (E6)	
7	Potential effect on buildings, built structures due to climate change (E7)	
8	Sinkholes formation by the method employed for mining (E8)	
9	Energy consumption (E9)	
10	Water depletion (E10)	
11	Mineral source depletion (E11)	
12	Fossil fuel depletion (E12)	
13	Particulate matter formation by mineral dust (coarse particles) and engine emissions (fine particles) (E13)	
14	Greenhouse gas emissions (E14)	
15	Photochemical oxidant formation (E15)	
16	Inappropriate labour cost (O1)	
17	Lack of raw material (O2)	
18	Lack of skilled labourers (O3)	
19	Lack of automation (O4)	
20	Lack of profitability / income generation (O5)	
21	Improper consumption pattern (O6)	
22	Lack of capital availability and usage (O7)	
23	Lack of equipment renovation & recyclability (O8)	
24	Inadequacy of training and competence (O9)	
25	Lack of emergency preparedness and response (O10)	
26	Inadequate grievance mechanism (O11)	
27	Lack of transparency in dissemination / data (O12)	
28	Lack of innovation (O13)	
29	Improper working conditions (O14)	
30	Unfair wages (O15)	
31	Work stress of employees and their shift work (S1)	
32	Unemployment (S2)	
33	Displacement of people (S3)	
34	Sustainable regional social protection system (S4)	
35	Lack of occupational health and safety practices (S5)	
36	Labour and management relations (S6)	
37	Lack of diversity and equal opportunity (S7)	
38	Poverty of local community (S8)	
39	Lack of work/life balance (S9)	
40	Lack of freedom for human rights (S10)	
41	Gender equity (S11)	
42	Lack of involvement of local community (S12)	
43	Lack of social inclusion in mining industry (S13)	
44	Lack of cultural diversity (S14)	
45	Involvement of child labour (S15)	

Table A3
Experts' profiles.

Experts	Designation	Department	Experience (years)
1	Chief Manager	Business Development Mining	15
2	Controller of Mines (Operations)	Mining operations	22
3	Controller of Mines (Planning & Coordination)	Planning and Coordination	20
4	Supply chain manager	Logistic and supply chain management	13
5	Deputy Manager	Quality Assurance & Inspection	10
6	Academician	Mining Engineering	11
7	Supervisor	Mining Operations	10
8	Executive Director	Human Resources	20

Table A4
Fuzzy linguistic scale used in this study.

Five-point score for decision makers' preference	Linguistic constants and their description	Trapezoidal fuzzy numbers (TrapFN) for equivalent scores
0	No influence	(0,0,0.1,0.2)
1	Very Low Influence	(0.1, 0.2, 0.3, 0.4)
2	Low Influence	(0.3, 0.4, 0.5, 0.6)
3	High Influence	(0.5, 0.6, 0.7, 0.8)
4	Very High Influence	(0.7, 0.8, 0.9, 1)

Appendix B

Fuzzy assessment data is provided by the experts for pairwise comparisons between important challenges of environmental, operational, and social challenges in mining industry. Based on the collected data, Fuzzy assessment matrix, direct relationship matrix, normalized matrix, and total relationship matrix have been calculated and they are given in the Appendix Tables B1, B2, B3, B4, B5, B6, B7, B8, B9, B10, B11, and B12.

Table B1
Fuzzy assessment matrix for environmental challenges.

	E1	E2	E3	E4	E5	E6	E7	E8
E1	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
E2	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
E3	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00
E4	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
E5	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
E6	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
E7	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.00,0.00,0.10,0.20	0.50,0.60,0.70,0.80
E8	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.00,0.00,0.10,0.20
E9	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.10,0.20,0.30,0.40	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
E10	0.50,0.60,0.70,0.80	0.10,0.20,0.30,0.40	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
E11	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.10,0.20,0.30,0.40	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60
E12	0.50,0.60,0.70,0.80	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60
E13	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60
E14	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60
E15	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60

	E9	E10	E11	E12	E13	E14	E15
E1	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
E2	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60
E3	0.10,0.20,0.30,0.40	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80
E4	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
E5	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
E6	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
E7	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
E8	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
E9	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
E10	0.30,0.40,0.50,0.60	0.00,0.00,0.10,0.20	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80
E11	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60
E12	0.70,0.80,0.90,1.00	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.00,0.00,0.10,0.20	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80
E13	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.00,0.00,0.10,0.20	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60
E14	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.30,0.40,0.50,0.60	0.00,0.00,0.10,0.20	0.30,0.40,0.50,0.60
E15	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.00,0.00,0.10,0.20

Table B2
Fuzzy assessment matrix for operational challenges.

	O1	O2	O3	O4	O5	O6	O7	O8
O1	0.00,0.00,0.10,0.20	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00
O2	0.10,0.20,0.30,0.40	0.00,0.00,0.10,0.20	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
O3	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
O4	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80
O5	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80
O6	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00
O7	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00
O8	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.10,0.20,0.30,0.40	0.00,0.00,0.10,0.20
O9	0.70,0.80,0.90,1.00	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40
O10	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00
O11	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60
O12	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40
O13	0.70,0.80,0.90,1.00	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00
O14	0.70,0.80,0.90,1.00	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40
O15	0.50,0.60,0.70,0.80	0.10,0.20,0.30,0.40	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60

	O9	O10	O11	O12	O13	O14	O15
O1	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
O2	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60
O3	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
O4	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60
O5	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80
O6	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80
O7	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
O8	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
O9	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
O10	0.50,0.60,0.70,0.80	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
O11	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
O12	0.10,0.20,0.30,0.40	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
O13	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
O14	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.50,0.60,0.70,0.80
O15	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.00,0.00,0.10,0.20

Table B3
Fuzzy assessment matrix for social challenges.

	S1	S2	S3	S4	S5	S6	S7	S8
S1	0.00,0.00,0.10,0.20	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00
S2	0.10,0.20,0.30,0.40	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60
S3	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60
S4	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80
S5	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80
S6	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00
S7	0.10,0.20,0.30,0.40	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00
S8	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.50,0.60,0.70,0.80	0.10,0.20,0.30,0.40	0.00,0.00,0.10,0.20
S9	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40
S10	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00
S11	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
S12	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
S13	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
S14	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
S15	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00

	S9	S10	S11	S12	S13	S14	S15
S1	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60
S2	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40
S3	0.10,0.20,0.30,0.40	0.50,0.60,0.70,0.80	0.10,0.20,0.30,0.40	0.50,0.60,0.70,0.80	0.10,0.20,0.30,0.40	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60
S4	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80
S5	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.30,0.40,0.50,0.60
S6	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80	0.50,0.60,0.70,0.80
S7	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.10,0.20,0.30,0.40
S8	0.50,0.60,0.70,0.80	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
S9	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.10,0.20,0.30,0.40
S10	0.50,0.60,0.70,0.80	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
S11	0.30,0.40,0.50,0.60	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00
S12	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
S13	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.70,0.80,0.90,1.00	0.50,0.60,0.70,0.80
S14	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.70,0.80,0.90,1.00	0.00,0.00,0.10,0.20	0.50,0.60,0.70,0.80
S15	0.10,0.20,0.30,0.40	0.70,0.80,0.90,1.00	0.30,0.40,0.50,0.60	0.10,0.20,0.30,0.40	0.10,0.20,0.30,0.40	0.50,0.60,0.70,0.80	0.00,0.00,0.10,0.20

Table B4
Fuzzy initial direct relation matrix (FDRM) of environmental challenges in mining industry.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
E1	0	4	4	3	3	3	4	4	3	3	3	4	4	4	4
E2	4	0	4	4	4	4	4	3	3	3	2	2	3	3	2
E3	3	2	0	4	4	4	3	4	1	2	2	2	3	3	3
E4	3	3	4	0	4	4	4	4	3	4	3	2	4	4	4
E5	3	4	4	2	0	4	4	4	3	3	3	3	4	4	4
E6	4	4	4	3	4	0	4	4	4	3	3	3	4	4	4
E7	4	4	3	3	4	2	0	3	3	4	4	4	3	4	3
E8	2	4	3	4	4	4	3	0	4	4	4	4	4	4	4
E9	4	3	1	2	4	4	4	3	0	4	3	4	3	4	3
E10	3	1	3	2	2	2	4	3	2	0	2	2	3	3	3
E11	2	3	1	2	3	2	4	2	1	1	0	4	2	2	2
E12	3	1	1	1	4	2	4	2	4	1	1	0	3	3	3
E13	2	4	4	3	3	2	4	2	2	1	1	1	0	2	2
E14	2	4	3	4	3	2	4	2	2	1	1	1	2	0	2
E15	2	4	3	3	3	2	4	2	2	1	1	1	2	3	0

Table B5
Fuzzy initial direct relation matrix (FDRM) for operational challenges in mining industry.

	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15
O1	0	2	4	4	4	4	3	4	3	3	3	2	4	4	3
O2	1	0	2	4	4	3	4	4	1	1	1	3	4	3	2
O3	4	2	0	4	4	3	4	4	4	4	4	2	4	4	3
O4	4	2	4	0	3	3	2	3	3	3	3	3	3	3	2
O5	4	4	1	4	0	4	2	3	3	3	2	3	3	2	3
O6	2	4	1	4	4	0	3	4	4	3	4	4	3	3	3
O7	3	3	3	4	4	4	0	4	2	4	4	4	4	4	3
O8	1	1	1	4	4	3	1	0	3	4	3	2	4	4	4
O9	4	1	4	4	4	2	1	1	0	4	4	4	4	4	3
O10	3	3	4	3	4	2	3	4	3	0	4	4	4	4	4
O11	2	1	4	2	4	2	3	2	3	2	0	4	4	4	4
O12	2	1	2	2	4	2	2	1	1	3	2	0	4	4	3
O13	4	1	4	4	4	2	3	4	4	4	4	4	2	4	3
O14	4	1	4	4	4	2	2	1	4	4	4	2	4	0	3
O15	3	1	2	3	4	3	2	2	4	2	4	2	4	3	0

Table B6
Fuzzy initial direct relation matrix (FDRM) for social challenges in mining industry.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	0	3	2	4	4	3	3	4	4	3	4	3	4	2	2
S2	1	0	4	4	4	3	2	2	3	3	2	2	3	2	1
S3	1	4	0	4	4	4	2	2	1	3	1	3	1	3	2
S4	3	4	4	0	3	3	2	3	3	3	3	3	3	3	3
S5	1	4	3	4	0	4	2	3	3	3	2	3	3	2	2
S6	4	3	4	4	4	0	3	4	4	3	4	4	3	3	3
S7	1	2	1	1	1	4	0	4	2	4	4	4	4	4	1
S8	1	1	1	1	1	3	1	0	3	4	3	2	4	4	4
S9	1	1	1	1	1	4	1	1	0	4	4	4	4	4	1
S10	2	3	3	4	4	4	3	4	3	0	4	4	4	4	4
S11	2	1	1	1	1	4	4	3	2	4	0	4	4	4	4
S12	2	1	1	1	1	4	4	4	1	4	3	0	4	4	3
S13	2	1	1	1	1	4	4	4	1	4	4	4	0	4	3
S14	2	1	1	1	1	4	4	3	1	4	4	4	4	0	3
S15	2	1	1	1	1	4	2	4	1	4	2	1	1	3	0

Table B7
Fuzzy normalized direct relation matrix (NDRM) for environmental challenges in mining industry.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
E1	0.006	0.073	0.073	0.056	0.056	0.056	0.073	0.073	0.056	0.056	0.056	0.073	0.073	0.073	0.073
E2	0.073	0.006	0.073	0.073	0.073	0.073	0.073	0.056	0.056	0.056	0.039	0.039	0.056	0.056	0.039
E3	0.056	0.039	0.006	0.073	0.073	0.073	0.056	0.073	0.022	0.039	0.039	0.039	0.056	0.056	0.056
E4	0.056	0.056	0.073	0.006	0.073	0.073	0.073	0.073	0.056	0.073	0.056	0.039	0.073	0.073	0.073
E5	0.056	0.073	0.073	0.039	0.006	0.073	0.073	0.073	0.056	0.056	0.056	0.056	0.073	0.073	0.073
E6	0.073	0.073	0.073	0.065	0.073	0.006	0.073	0.073	0.073	0.056	0.056	0.056	0.073	0.073	0.073
E7	0.073	0.073	0.056	0.056	0.073	0.039	0.006	0.056	0.056	0.073	0.073	0.073	0.065	0.073	0.056
E8	0.039	0.073	0.056	0.073	0.073	0.073	0.056	0.006	0.073	0.073	0.073	0.073	0.073	0.073	0.073
E9	0.073	0.056	0.022	0.039	0.073	0.073	0.073	0.056	0.006	0.073	0.056	0.073	0.056	0.073	0.056
E10	0.056	0.022	0.056	0.039	0.039	0.039	0.073	0.056	0.039	0.006	0.039	0.039	0.056	0.056	0.056
E11	0.039	0.056	0.022	0.039	0.056	0.039	0.073	0.039	0.022	0.022	0.006	0.073	0.039	0.039	0.039
E12	0.056	0.022	0.022	0.022	0.073	0.039	0.073	0.039	0.073	0.022	0.022	0.006	0.056	0.056	0.056
E13	0.039	0.073	0.073	0.056	0.056	0.039	0.073	0.039	0.039	0.022	0.022	0.022	0.006	0.039	0.039
E14	0.039	0.073	0.056	0.073	0.056	0.039	0.073	0.039	0.039	0.022	0.022	0.022	0.039	0.006	0.039
E15	0.039	0.073	0.056	0.056	0.056	0.039	0.073	0.039	0.039	0.022	0.022	0.022	0.039	0.056	0.006

Table B8
Fuzzy normalized direct relation matrix (NDRM) for operational challenges in mining industry.

	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15
O1	0.006	0.038	0.072	0.072	0.072	0.072	0.055	0.072	0.055	0.055	0.055	0.038	0.072	0.072	0.055
O2	0.021	0.006	0.038	0.072	0.072	0.055	0.072	0.072	0.021	0.021	0.021	0.055	0.072	0.055	0.038
O3	0.072	0.038	0.006	0.072	0.072	0.055	0.072	0.072	0.072	0.072	0.072	0.038	0.072	0.072	0.055
O4	0.072	0.038	0.072	0.006	0.055	0.055	0.038	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.038
O5	0.072	0.072	0.021	0.072	0.006	0.072	0.038	0.055	0.055	0.055	0.038	0.055	0.055	0.038	0.055
O6	0.038	0.072	0.021	0.072	0.072	0.006	0.055	0.072	0.072	0.055	0.072	0.072	0.055	0.055	0.055
O7	0.055	0.055	0.055	0.072	0.072	0.072	0.006	0.072	0.038	0.072	0.072	0.072	0.072	0.072	0.055
O8	0.021	0.021	0.021	0.072	0.072	0.055	0.021	0.006	0.055	0.072	0.055	0.038	0.072	0.072	0.072
O9	0.072	0.021	0.072	0.072	0.072	0.038	0.021	0.021	0.006	0.072	0.072	0.072	0.072	0.072	0.055
O10	0.055	0.055	0.072	0.055	0.072	0.038	0.055	0.072	0.055	0.006	0.072	0.072	0.072	0.072	0.072
O11	0.038	0.021	0.072	0.038	0.072	0.038	0.055	0.038	0.055	0.038	0.006	0.072	0.072	0.072	0.072
O12	0.038	0.021	0.038	0.038	0.072	0.038	0.038	0.021	0.021	0.055	0.038	0.006	0.072	0.072	0.055
O13	0.072	0.021	0.072	0.072	0.072	0.038	0.055	0.072	0.072	0.072	0.072	0.072	0.038	0.072	0.055
O14	0.072	0.021	0.072	0.072	0.072	0.038	0.038	0.021	0.072	0.072	0.072	0.038	0.072	0.006	0.055
O15	0.055	0.021	0.038	0.055	0.072	0.055	0.038	0.038	0.072	0.038	0.072	0.038	0.072	0.055	0.006

Table B9
Fuzzy normalized direct relation matrix (NDRM) for social challenges in mining industry.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	0.007	0.058	0.040	0.076	0.076	0.058	0.058	0.076	0.076	0.058	0.076	0.058	0.076	0.040	0.040
S2	0.022	0.007	0.076	0.076	0.076	0.058	0.040	0.040	0.058	0.058	0.040	0.040	0.058	0.040	0.022
S3	0.022	0.076	0.007	0.076	0.076	0.076	0.040	0.040	0.022	0.058	0.022	0.058	0.022	0.058	0.040
S4	0.058	0.076	0.076	0.007	0.058	0.058	0.040	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
S5	0.022	0.076	0.058	0.076	0.007	0.076	0.040	0.058	0.058	0.058	0.040	0.058	0.058	0.040	0.040
S6	0.076	0.058	0.076	0.076	0.076	0.007	0.058	0.076	0.076	0.058	0.076	0.076	0.058	0.058	0.058
S7	0.022	0.040	0.022	0.022	0.022	0.076	0.007	0.076	0.040	0.076	0.076	0.076	0.076	0.076	0.022
S8	0.022	0.022	0.022	0.022	0.022	0.058	0.022	0.007	0.058	0.076	0.058	0.040	0.076	0.076	0.076
S9	0.022	0.022	0.022	0.022	0.022	0.076	0.022	0.022	0.007	0.076	0.076	0.076	0.076	0.076	0.022
S10	0.040	0.058	0.058	0.076	0.076	0.076	0.058	0.076	0.058	0.007	0.076	0.076	0.076	0.076	0.076
S11	0.040	0.022	0.022	0.022	0.022	0.076	0.076	0.058	0.040	0.076	0.007	0.076	0.076	0.076	0.076
S12	0.040	0.022	0.022	0.022	0.022	0.076	0.076	0.076	0.022	0.076	0.058	0.007	0.076	0.076	0.058
S13	0.040	0.022	0.022	0.022	0.022	0.076	0.076	0.076	0.022	0.076	0.076	0.076	0.007	0.076	0.058
S14	0.040	0.022	0.022	0.022	0.022	0.076	0.076	0.058	0.022	0.076	0.076	0.076	0.076	0.007	0.058
S15	0.040	0.022	0.022	0.022	0.022	0.076	0.040	0.076	0.022	0.076	0.040	0.022	0.022	0.058	0.007

Table B10
Fuzzy total relation matrix (TRM) for environmental challenges in mining industry.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
E1	0.239	0.325	0.311	0.288	0.327	0.287	0.364	0.307	0.268	0.258	0.248	0.280	0.320	0.332	0.311
E2	0.289	0.246	0.297	0.288	0.324	0.289	0.345	0.279	0.254	0.247	0.222	0.237	0.290	0.301	0.266
E3	0.250	0.256	0.212	0.267	0.299	0.266	0.302	0.271	0.204	0.212	0.203	0.216	0.266	0.276	0.260
E4	0.289	0.313	0.314	0.242	0.343	0.304	0.366	0.310	0.269	0.276	0.250	0.251	0.322	0.334	0.314
E5	0.284	0.323	0.308	0.269	0.275	0.299	0.360	0.304	0.265	0.255	0.245	0.262	0.316	0.328	0.308
E6	0.315	0.340	0.324	0.308	0.356	0.253	0.380	0.321	0.295	0.270	0.259	0.277	0.334	0.347	0.325
E7	0.295	0.317	0.287	0.279	0.333	0.264	0.293	0.284	0.261	0.267	0.257	0.275	0.305	0.324	0.288
E8	0.279	0.333	0.303	0.309	0.350	0.310	0.359	0.252	0.290	0.280	0.269	0.287	0.328	0.340	0.319
E9	0.288	0.294	0.248	0.255	0.323	0.286	0.345	0.276	0.207	0.261	0.236	0.268	0.288	0.316	0.281
E10	0.225	0.212	0.232	0.210	0.239	0.209	0.286	0.229	0.195	0.157	0.182	0.194	0.238	0.248	0.232
E11	0.195	0.225	0.184	0.193	0.236	0.193	0.266	0.197	0.167	0.159	0.136	0.212	0.206	0.214	0.200
E12	0.219	0.206	0.193	0.187	0.262	0.203	0.278	0.207	0.222	0.168	0.161	0.157	0.232	0.241	0.226
E13	0.207	0.254	0.245	0.223	0.251	0.208	0.281	0.211	0.192	0.171	0.163	0.174	0.187	0.228	0.213
E14	0.208	0.255	0.230	0.239	0.251	0.208	0.282	0.212	0.193	0.173	0.164	0.175	0.220	0.197	0.213
E15	0.206	0.254	0.229	0.223	0.250	0.207	0.280	0.210	0.191	0.171	0.162	0.174	0.218	0.243	0.180

Table B11
Fuzzy total relation matrix (TRM) for operational challenges in mining industry.

	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12	O13	O14	O15
O1	0.236	0.192	0.289	0.333	0.356	0.280	0.244	0.289	0.286	0.294	0.302	0.269	0.356	0.332	0.286
O2	0.205	0.130	0.212	0.281	0.298	0.223	0.221	0.245	0.207	0.215	0.220	0.239	0.299	0.263	0.223
O3	0.311	0.200	0.241	0.348	0.372	0.277	0.270	0.301	0.314	0.323	0.332	0.283	0.373	0.348	0.300
O4	0.271	0.173	0.264	0.240	0.307	0.240	0.207	0.248	0.258	0.265	0.273	0.258	0.308	0.287	0.244
O5	0.267	0.204	0.214	0.299	0.257	0.254	0.204	0.246	0.254	0.261	0.253	0.256	0.304	0.268	0.256
O6	0.255	0.216	0.233	0.321	0.344	0.209	0.235	0.278	0.289	0.282	0.305	0.292	0.329	0.306	0.276
O7	0.291	0.214	0.283	0.344	0.369	0.289	0.206	0.298	0.280	0.319	0.328	0.311	0.370	0.345	0.297
O8	0.216	0.150	0.208	0.290	0.310	0.229	0.181	0.189	0.250	0.270	0.263	0.233	0.310	0.289	0.265
O9	0.286	0.165	0.279	0.316	0.339	0.235	0.202	0.227	0.225	0.294	0.302	0.286	0.340	0.317	0.272
O10	0.288	0.209	0.295	0.324	0.364	0.254	0.249	0.293	0.291	0.252	0.323	0.306	0.365	0.340	0.308
O11	0.241	0.156	0.263	0.270	0.322	0.223	0.221	0.229	0.258	0.250	0.226	0.273	0.323	0.301	0.274
O12	0.207	0.135	0.200	0.231	0.279	0.192	0.178	0.183	0.193	0.229	0.220	0.176	0.280	0.261	0.224
O13	0.315	0.185	0.307	0.351	0.376	0.263	0.257	0.303	0.318	0.327	0.336	0.317	0.345	0.352	0.303
O14	0.284	0.165	0.277	0.314	0.336	0.234	0.216	0.226	0.286	0.292	0.301	0.254	0.337	0.252	0.270
O15	0.248	0.151	0.225	0.276	0.312	0.231	0.198	0.222	0.266	0.241	0.279	0.235	0.312	0.276	0.204

Table B12
Fuzzy total relation matrix (TRM) for social challenges in mining industry.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1	0.139	0.200	0.178	0.225	0.221	0.300	0.241	0.290	0.231	0.293	0.287	0.274	0.295	0.263	0.223
S2	0.132	0.130	0.190	0.202	0.199	0.258	0.191	0.218	0.186	0.251	0.215	0.220	0.238	0.223	0.173
S3	0.130	0.193	0.125	0.201	0.198	0.270	0.189	0.216	0.152	0.247	0.195	0.231	0.201	0.235	0.187
S4	0.182	0.211	0.206	0.156	0.201	0.290	0.216	0.264	0.206	0.282	0.260	0.263	0.267	0.268	0.230
S5	0.140	0.201	0.181	0.210	0.142	0.288	0.202	0.248	0.195	0.265	0.228	0.248	0.251	0.236	0.201
S6	0.216	0.214	0.224	0.240	0.236	0.275	0.258	0.310	0.245	0.315	0.306	0.310	0.298	0.300	0.256
S7	0.136	0.157	0.138	0.149	0.147	0.280	0.168	0.260	0.172	0.275	0.258	0.259	0.264	0.265	0.182
S8	0.124	0.128	0.125	0.135	0.133	0.242	0.165	0.175	0.173	0.254	0.221	0.205	0.241	0.244	0.214
S9	0.125	0.128	0.125	0.136	0.134	0.258	0.168	0.190	0.124	0.253	0.238	0.240	0.242	0.243	0.164
S10	0.184	0.213	0.207	0.238	0.234	0.340	0.259	0.311	0.227	0.267	0.306	0.309	0.314	0.316	0.274
S11	0.157	0.146	0.141	0.154	0.151	0.289	0.239	0.252	0.176	0.283	0.200	0.265	0.269	0.272	0.236
S12	0.152	0.141	0.137	0.149	0.147	0.280	0.232	0.261	0.155	0.275	0.241	0.193	0.262	0.264	0.214
S13	0.155	0.144	0.139	0.152	0.149	0.285	0.236	0.265	0.158	0.279	0.261	0.262	0.202	0.268	0.218
S14	0.153	0.141	0.137	0.149	0.147	0.281	0.233	0.245	0.155	0.275	0.257	0.258	0.262	0.200	0.214
S15	0.129	0.119	0.116	0.126	0.124	0.236	0.164	0.221	0.130	0.232	0.185	0.169	0.173	0.207	0.133

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