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Management of methane emission in coal mines using artificial neural networks: A systematic review

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Abstract

Underground mines are responsible for a large number of the released methane worldwide. Our study paper can contribute to mitigating methane emissions, hence reducing the concentration about greenhouse emissions within the environment and mitigating the associated hazardous risks. In this study, more than 45 recent journals on Methane emission in Coal Mines were gathered from Web of Science, IEEE Xplore, ScienceDirect, and ResearchGate. A systematic review is accomplished of the past four years of various parts of Methane gas emission such as anthropogenic emission sources, gas emissions detection, prediction of methane using different technology and the Artificial intelligence projection model for methane emission. The outcomes reveal that since the methane emission management has obtained increasing attention over the past four years. This study also shows that big countries are using technology to control and utilize the methane emission to reduce the energy crisis. To decrease the coal mine injuries, academic understanding of underground methane management has increased, different technologies are integrated and support from various IT departments has amplified for the forecasting. In the future, the most critical task for coal mines risk assessment is to restore the worker's trust in mine safety, and the primary solution is to give more awareness to the underground management and workers through utilizing Artificial Intelligence (AI) mainly Artificial Neural Networks (ANN).

Keywords: Coal mining; Methane emission; ANN; Risk assessment; Energy waste; Artificial intelligence

1. Introduction

Coal is one of the significant natural resources on the earth and it has a prevalent role in the entire preliminary energy of a country. Coal mines are playing a vital role in power resources on this planet. Coal exploitation also makes a significant donation to developing countries for their welfare and economy by generating purchasing power and providing employment opportunities. Nevertheless, the coal production system inside the coal mines is very complicated, which compels coal mine injuries (Tong et al. 2019) [1] Safety is a huge need in coal mining during its production phase. Underground coal mine mishaps render massive upsets to the economy of a country and are also accountable for all the deaths among coal miners. Methane casualties are commonly perceived as the most hazardous among various types of coal mine accidents (Zhou and Jiang 2016; Brodny and Tutak 2018; Krause E, Smoliński A 2013;) [2,3,4,] . In mine headings, high levels of methane concentration cause the risk of explosion and disrupt mining operations. In the last few years, Methane explosion in an underground mine has directed too many injuries related to methane explosion [5,6, 7, 8, 9, 10, 11, 12, and 13], this information is visible in Table 1.

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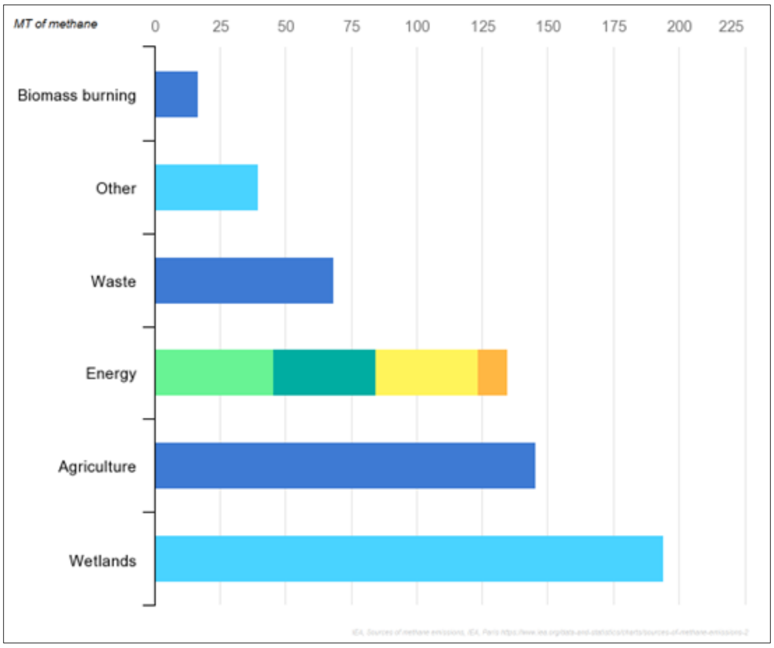
Table 1 Coal mine underground injuries associated with methane and other gas explosions

Time	Coal Mine/ Country	Reason behind Explosion	Fatalities
2005	Liaoning/ China	Methane gas blast	203
2006	Halemba/ Poland	Methane gas and dust blast	23
2007	Shanxi/ China	Methane gas blast	105
2009	Wujek/ Poland	Methane gas and dust blast	20
2009	Heilongjiang/ China	Methane gas blast and fire	104
2010	Zonguldak/ Turkey	Methane gas blast	30
2010	West Virginia/ America	Methane gas blast	25
2012	Xiaojiawan/ China	Methane gas blast	45
2014	Mysłowice-Wesoła/ Poland	Methane gas blast	5
2014	Soma/ Turkey	Methane fire and blast	301
2015	Sośnica/ Poland	Methane blast and fire	4
2016	Murcki-Staszic/ Poland	Methane gas blast	1
2018	Karvina/ Czech Republic	Methane gas blast	13
2021	Listvyazhnaya/ Russia	Methane gas blast	51
2022	Balochistan/ Pakistan	Methane and other gas explosion	4
2022	JSW's Pniowek/ Poland	Methane explosion	5

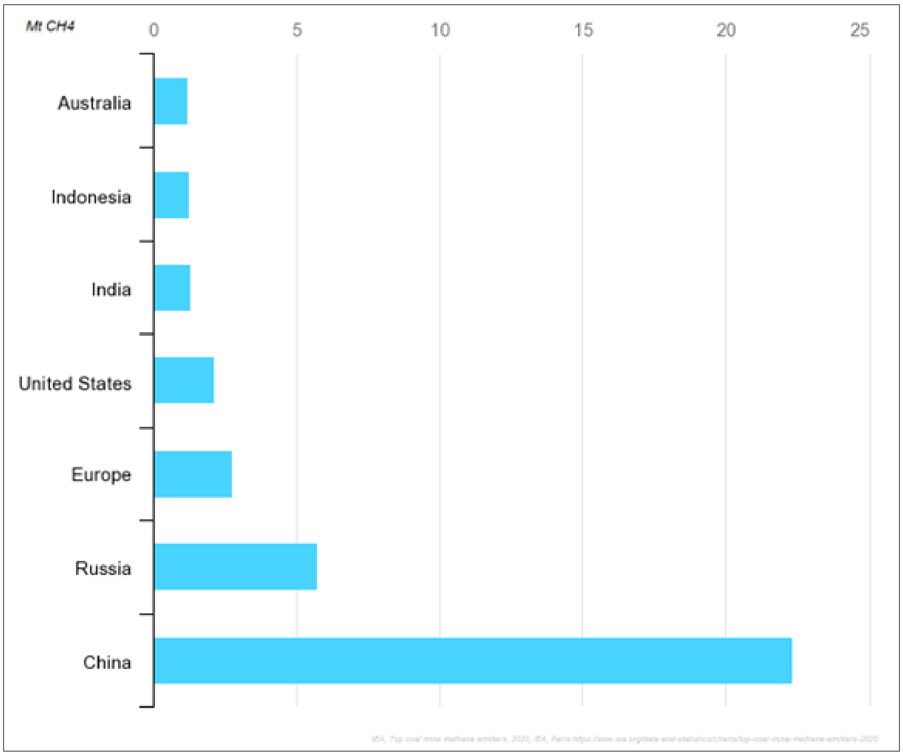
Methane is a highly flammable, greenhouse gas and it harms the environment [14]. Most methane emission is from underground coal mines particularly from abandoned coal mines [20] [41]. Other resources of the methane emission are shown in the Fig 1. The biggest origin of anthropogenic methane emissions is the industry of agriculture and it's almost a quarter of the total [21]. According to Global Energy Monitor (GEM), every year the coal mines around the world are radiating 52.3 million tons of methane [22].



Source: IEA https://earth.org/methane-bombs/

Figure 1 Sources of methane emissions

Chins is leading coal mine methane emitter following by Russia. China have emitted 22.31 Mt CH4 so far. On the other hand, Russia has emitted 5.7 Mt CH4 [23]. There is a huge difference between top 2 methane emitter.



Source: https://ember-climate.org/insights/commentary/why-the-world-must-act-on-coal-mine-methane/

Figure 2 Top coal mine methane emitters, October 2021

In the coal production process, a huge quantity of coal mines methane gas release into the atmosphere which leads to global warming and energy waste. Extreme and impulsive methane releases from coal mines cause equipment damage and casualties [15]. Lengthy exposure to methane gas causes the sudden death which is quite frequent inside the coal mine. It's important to understand geological, geographical, and operational factors to get the functional knowledge of methane emission [16]. The information given in the Table 1 originates from different resources of mining industry, which prints the total number of injuries of mine workers of coal explosion from 2005 to 2022.

From 2005 to 2022, very severe methane explosion tragedies have often arisen in different part of world. According to a report by the Pakistan Central Mine Labor Federation, the number of serious methane emission calamities reached 237 in 2022 [8]. The methane gas which is discharging in the process of mining is unbelievable, but a few sacks of methane are utilized every year. Hence, it is important to manage the methane emission and provide guidelines for coal mine support. By this way, a country can improve his economy and we can control the energy crisis. Sufficient control of the production of coal has great significance to defend the workers underground. Forecasting with different technology is becoming the primary method for safety management and risk assessment at present [19]. According to Olczak and Piebalgs [20], the uncertainty of methane gas emission coming out from coal mines are great, especially from abandoned mines. For the social advantages, we can utilize the coal-mine-methane and abandoned-mine-methane. The prediction of methane and other gas emissions is an interesting device to optimize production and safety. Which techniques is best one for prediction? Why do researchers use ANN? Because methane emission possesses a huge number of hardly accessible factors and non-linear physical laws. Which can be handled effectively by using ANN [16] [18] [55] [63] [64] [65] [67].

The primary aim of this research is to uncover the significant recent modifications and notable accomplishments in methane release analysis utilizing Artificial Neural Networks (ANN) within coal mines. It also includes an estimation of methane emissions to decommissioned coal mines. A few studies discussed the future of methane emissions and impact of emission on coal workers. Overall, this paper can improve our knowledge of present and future emissions.

2. Methodology for Systematic Review

A systematic literature review enables the arrangement and evaluation of all the problem statements and research objectives [68]. In this paper, we have designed the research questions to determine the dimensions and aim of our study. Afterward, a searching technique was prepared to discover all the studies associated with the research questions (RQs). Subsequently, the outcomes of this analysis were reviewed to uncover their applicability in coal mining. Based on the literature review of the most recent work by different researchers, this study delivers a systematic literature review of the methane prediction and future concerns in the coal mines. These research questions are debated:

- What changes in methane emission management using ANN have taken place in the past 4 years?
- RQ2: How did the estimations using ANN have affected the worker's life? What phases did these modifications go through?
- RQ3: What was the direction of each phase in the past four years and what will be the emphasis in the future?

This paper is going to give three contributions:

- This paper delivers a unique mindset on literature research. In recent four years, 46 highly appropriate references were nominated for a systematic literature review and these papers were classified by titles, topics, abstracts, and keywords.
- Recent achievements in methane emissions using ANN technology and coal mine safety management in the past 10 years were summarized based on literature practice.
- Future of coal mine safety to restore the workers' trust by enhancing regulatory techniques and shaping coal mine safety ethics.

2.1. Search Method

A specific keyword-based search procedure was adopted to have high influence, originality, and high standards in all the papers. Google Scholar and ResearchGate were used as search engines to search methane emissions in coal mines in the last four years. The starting search phrases used were 'methane emissions in coal mining, 'methane emissions prediction', 'management of methane emission', and 'Artificial intelligence projection model for methane emission'. The first 40 pages of Google Scholar were explored and the appropriate papers were collected. In the next step, the papers collected from keyword searches were examined and classified. Articles were diagnosed based on the year of publication, the study design, and the methods used. All the papers which do not follow our inclusion criteria are excluded from the selected article group. Inclusion and exclusion criteria are mentioned in Table 2. Different classifications were developed (Table 3) by focusing on abstract and keywords that the research concentrated most. We searched more than 230 papers and 46 papers were selected for the literature review finally. A flow chart of selection process can be seen in Figure 3 below.

Table 2 Inclusion Criteria and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Journals which are Peer reviewed and written in English language	Other than English languages
Studies Published in last 4 years	Before Jan 2018
Studies referring to methane emissions	Studies with insufficient focus on methane emissions
Research articles + conference papers + Literature Review	Reviews, Books and commentaries are excluded
Full text articles	Everything else is excluded

Table 3 Summary of collected papers

Sr No.	Parameter Addressed	No. of Papers
1	Methane Emissions in Coal Mining	43
2	Safety Management of Coal Mining	28
3	Prediction of Coal and Gas Outburst	30
4	Predicting Agricultural Methane Emissions	10
5	Methane Emissions from Abandoned Coal Mines	12
6	Artificial Intelligence Models Methane Prediction	18
7	Safety and Environmental Protection	28
8	Gas Accidents in Coal Mine	34
9	Prediction of Methane using Artificial Neural Networks	14
10	Literature Review on Coal Mining	18

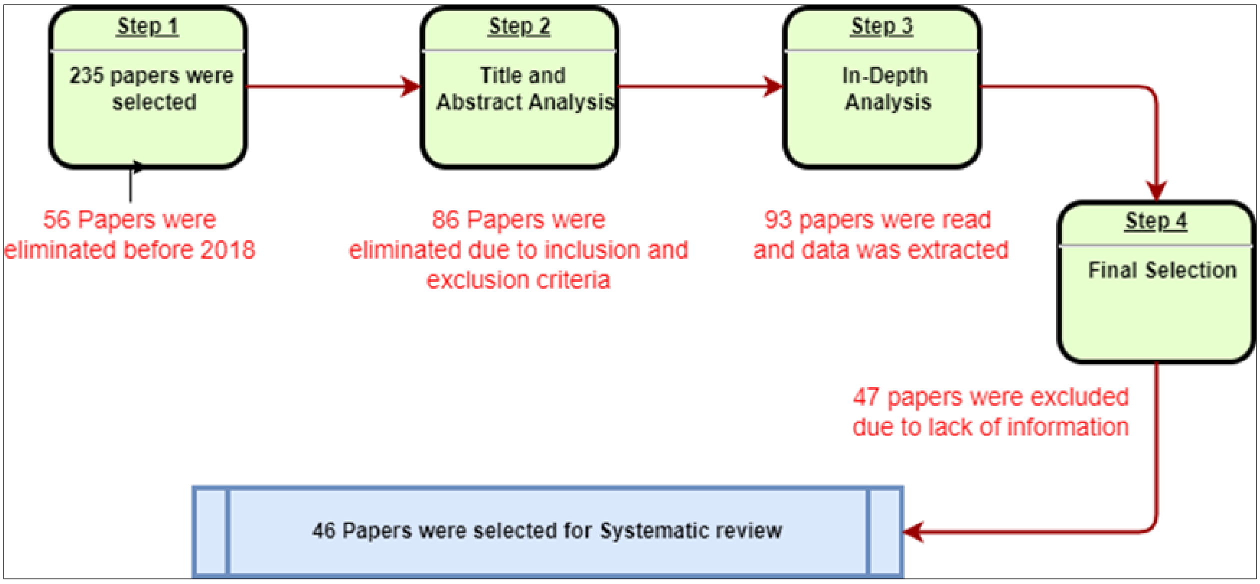


Figure 3 Flow chart of paper selection process

2.2. Inclusion and Exclusion Criteria

Our inclusion criteria reliably, consistently, and impartially identify the research population. Published papers are regarded as having satisfied the requirements for originality, significant influence, and high standards. This is due to the fact that such manuscripts are checked by professionals before being updated and published. We have chosen published papers as a result. The following were the selection criteria: Research papers, full text, and mineral processing exclusion are listed in that order. These standards were chosen because they allowed an accurate review of the paper's content and allowed only research articles to be utilized to examine the present state of ANN. We have excluded all the paper other than English language. The whole process of elimination is showed in the figure 3. All the 46 papers have the accurate information about what we are going to research. Top authors are showed in the table 4 below.

Table 4 Number of reviewed papers with top authors information

Years of Publication	Number of papers	Author
2020-2021	5	Justyna Swolkień
2022	2	Michael Coté
2020-2021	3	Junlian Gao
2021-2022	3	Andreas Luther
2021-2022	4	Pankaj Sadavarte
2021-2022	3	Anna-Leah Nickl
2019-2022	4	C. Özgen Karacan
2019-2020	2	Sello Mathatho
2019	3	Magdalena Tutak
2020	2	Nazar Kholod
2020	1	YUZHONG ZHANG
2019-2022	2	Sebnem Duzgun
2022	1	Doga Cagdas Demirkan
2021-2022	3	Marcin Dreger
2020	1	Nikodem Szlązak
2020	1	Jerzy Krawczyk

3. Results

Description of Included Paper

We have divided our description part into three major parts. Which will answer all the RQ1, RQ2 and RQ3.

3.1. Methane emission in Coal Mines – Literature review

Few academics have studied methane discharge and its management in coal mines. This section shows modifications to the release of methane (RQ1) with worker survival (RQ2) during the past four years.

Junlian et al. [24] found that methane emissions at over 10,000 Chinese coal mines decreased from 2010 until 2019. China reduced coal mine methane (CMM) production by 37% during 2010 and the year 2019, averaging 20.11 Tg with a downward trend of 0.93 Tg/yr. The 2012 CMM emissions surge was an anomaly in our analysis.

Pankaj et al. [25] observed subsurface methane gas production within Queensland, as well, Australia's largest coal producer. Australia's deep coal mines released 570 ± 98 Gg a-1 during 2018-2019, accounting for 7% for all coal production. These findings demonstrate the fact satellite-based assessments are much greater than the Australian government claims. Additionally, 40% from Hail Creek emissions of gases.

Andreas et al. [26] observed CH_4 emission within south Poland's Greater Silesian Coal Region. They used paired upwind–downwind measurements with 4 spectrometers throughout the CoMet activity throughout May–June 2018 for submitting methane emissions. Researchers identified trajectory-based simulation discrepancy for six cases. Windmills with uncertainty reported 23%–36% error variability.

A excellent quality 0.1° * 0.1° from the bottom up grids measuring emitted methane across Australia as well as India was given by Pankaj et al. [27] This article improves geographical localization to reduce methane gas production. India improved emission spatial distribution using tier-2 IPCC approach. They predicted methane emissions for each Australian coal mine using coal production proxy. The changed spatial distribution affected both countries differently.

Marcin and Sławomir [28] reported methane levels and releases in two Polish coal mining operations. During 2016, Budryk mining CH4 emissions topped a total of 140 m3. Pniówek mining methane emissions rose from 1986 to 1991. Later, emissions dropped below fourteen million m3. Coal mining methane emissions vary according to natural variables like gas flow and geography.

In recent years, Polish miners have emitted more methane, according to Nikodem et al. [29]. The expansion is due to gassy coal deposits. Experts said methane emissions will remain the same next year. The proposed primary methane hazard could decrease risks and increase safety.

World-leading methane emission is China. During 2010 until 2017, Jianxiong et al. [30] observed a linear trend of 0.36 ± 0.04 ($\pm1\sigma$) Tg CH4 yr^{-2} within methane emissions. China's post-2010 methane policies were generally ineffectual. The proportion of decrease was -0.1 ± 0.04 Tg CH4 yr^{-3}. Yet, greenhouse gas emissions did not decrease in as little as coal.

Coté along with M.Collings[31] discovered that nonce countries include mines that have been in releases of greenhouse gases. EPA calculates releases gases from derelict U.S. coal seams. The results show that inactive mine pollutants make up 5% of U.S. output. They stated other countries may use the same technology to calculate methane accurately.

Jones et al. [32] calculated global underlying CH4. Beneath mining gob wells, evacuation shafts, plus crushing activities release CH4. Always, ventilation air causes most mining outputs. Gob wells aid in longwall mining emissions below.

Qingjie Qi et al. [33] calculated unusual release of methane in coalfields during Laohutai quakes using seismicity-induced susceptibility change. Peak grounding velocities (PGVs), residual coalfield methane challenges, seismic acceleration values, and the earliest mining seam permeabilities affect earthquake-induced the gas methane releases. Methane within the airflow increases with PGV, whereas seismic acceleration decreases it.

Gao et al. [37] discussed bottom-up calculation, the final one four years, including China's CMM production limits. In 1980 until 2016, CMM output reached 16.41 Tg, up 21.48 Tg. Additional focus is needed for reliable outcomes.

Decreased coal and natural gas release of methane can help global warming. Varon et al. [38] identified and quantified substantial gas production energy sources across Central Asia using satellite technologies. Global methane hot areas can be identified with GHGSat-D, leading to significant reduction in emissions.

Kholod et al. [41] predicted global methane through coal mining given increasing depth along with extraction methods by 2100. The article estimated fugitive emissions using modern methods. When researching coal, extract method, mine depths, coal rank, plus evidence-based greenhouse gases factors are considered. Higher coals mining-related releases of methane were found in 2010. The following piece estimated methane emissions from disused coal mines using a unique method. Unoccupied underground mines increase methane emissions about 4 times, whereas abandoned mines increase them by 8.

An approach used to define train traffic in tunnels was transformed into a precise layout of an entire longwall district by Krawczyk [42]. Both air-methane combination was calculated using the limited volume approach and k-w SST plus SAS turbulence simulations.

Diaz et al. [68] used Atmospheric Surveillance Systems information to anticipate a gas called methane levels in Eastern US coal mines that were underground. Cleaning up information and filtering, categorization, homogenization, and experimental statistical analysis were used.

Table 5 Literature Review of Methane emission in Coal Mines

Research Work		**Trend in methane emission**	**Country**	**Contribution of the paper**	**Useful results**
Title	**MM-YYYY**				
"Reducing methane emissions to China's coal mines while increasing coal production."	12-2021	Decreasing	China	Calculating CMM emissions of China	Emissions decreased by 37% between 2010 and 2019
"Australian Super emitting Coal Mining Methane Releases Quantified by TROPOMI Satellite Data"	11-2021	Increasing	Australia-Queensland	Methane Emissions Using TROPOMI Satellite Observations	Satellite-based calculations are quite higher
"Quantifying the emission of methane to Polish mining operations through a ground-based sensor networking: observational constraints"	12-2021	Increasing	Poland-USCB	Observations of each pair of upward and downstream winds by an ensemble of four movable, sun-viewing, ground-based Fourier Transformation Spectrometers that are of the EM27/SUN sort in June or May 2018.	Reporting more emissions than expected compared to the total emissions reported through the E-PRTR.
"An accurate and detailed record of coal-mine greenhouse gas emissions in both countries, presented in an organized format with high resolution." (India plus Australia)	07-2022	Decreasing	India, Australia	A fully functional dataset for climate-modelling air-quality	825 Gg a-1 methane-emissions for IND | 972 Gg a-1 methane emission for AUS
"Methane emissions from the Budryk plus Pniówek miners in the Upper-Silesian-Coal-Basin (the nation of Poland) with relation to both natural and artificial mining conditions."	11-2021	Decreasing	Poland	The length of digging longwalls, the extent of mining for coal, the variety of longwalls, plus the presence of goafs have been identified as factors contributing significantly to methane emissions.	Methane emissions tend to coincide with the increase in the extent of coal exploitation.
"A Comprehensive Analysis of Safety Measures in Polish Heavy Methane Coal Mining"	02-2020	Decreasing	Poland	The design of longwall panels can help in both forecasting methane-emission and prediction of other ventilation-related hazards.	Methane hazard prevention is linked with underground ventilation.
"China has continued to release methane into the atmosphere after 2012, even though there has been a decrease in the	10-2021	Increasing	China	Additional methane emissions may be attributed to abandoned coal mining operations as well as locations that	The fall in China's extraction of coal has contributed to the decline in the growth rate.

extraction of coal and the area used for rice cultivation."				practice rice-growing another aquaculture farming.	
"Estimated Methane Emissions along with Methodology for Deserted Coal Mines across the United States."	07-2022	Increasing	USA	greenhouse gas emissions should include abandoned mines for accurate calculations	Abandoned mining emissions account for five percent of the overall emissions throughout the United States.
"Initial findings upon a method over estimating methane emissions from underground coal mines"	07-2022	Increasing	USA	Combines information on the characteristics of coal, the amount of coal produced, the methane content in coalbeds, and the emissions of ventilation air from coal mines.	Estimated methane-emissions globally
"Modelling and simulating the effects of earthquakes on methane emissions from the active area in an interior coal mine."	03-2022	Increasing	China	Implement proactive efforts to mitigate methane-related incidents within coal mines caused by earthquakes.	PGVs, residual mined methane challenges, seismic acceleration values, and starting coal-seam porosity affect the release of methane during earthquakes.
"A critical analysis of current grassroots inventory of China's methane emissions through coal mining"	04-2020	Increasing	China	a synopsis of bottom-up prediction of China's CMM releases	The emissions experienced a significant increase between 4.64 through 16.41 Tg, with a notable growth of 21.48 Tg between the years 1980 and 2016.
"Detection of Abnormally Large Methane Emissions from Oil and Gas Production Using Satellite Technology"	11-2019	Increasing	Central Asia	Use satellite instruments to observe methane emissions	Spotted hot spots for methane emissions in Central Asia
"Despite a decrease in the production of coal, the worldwide emissions of methane by mining for coal are projected to keep increasing."	11-2020	Increasing	Global	Projected methane emissions during coal mining are expected to increase as mining operations reach greater depths until the year 2100.	Methane releases from operational underground mines increase by an amount of 4, whereas methane emissions for abandoned mines increase by a ratio of 8.
"An initial investigation into specific techniques for modelling the impact of shearer action on the spread of methane or	04-2020	----	----	the finite volume method to calculate the methane emission	two hypothetical cases are presented in the paper

airflow in longwall mining."					
My research involves studying the correlation between emissions of methane and environmental information from coal mines beneath the ground in order to create a predictive model.	03-2022	----	USA	The amount of methane level is determined by analyzing data obtained from Environmental Monitoring Systems.	The relationship between gas concentration along with other elements associated with mine operations including design.

3.2. Prediction of Methane emission in Coal Mines - Literature Review

Utilizing forecasting and foresight methodologies is the most effective means to prevent or regulate methane emissions. Due to the rapid growth of technological advances in recent times, artificial intelligence along with deep training have mostly been employed for the purpose monitoring methane emission prediction. The next part will examine the utilization of several computational approaches through researchers to study emissions of methane within coal mines. Each presentation also proposed the implementation of novel technologies and safety protocols that will assist us in addressing our research questions RQ2 through RQ3.

Doga et al. [34] assessed the efficacy of artificial intelligence (AI) to anticipate real-time explosion hazards. Seven distinct data sets were employed to evaluate the predictive capabilities of ten time-varying algorithms. The HIVE-COTE, ROCKET, along with RISE algorithms provided precise and up-to-the-minute methane forecasts. The utilization of artificial intelligence (AI) modeling to analyze explosive dangers, together with the implementation of advanced monitoring systems (AMS) sensors, has the potential to enhance the security of mines.

Anna and her colleagues [35] utilized trustworthy chemistry-climate systems and extensive measurement efforts to thoroughly examine the worldwide methane. The quantification of methane emissions during coal mining within the Upland Silesian Coal Basin (USCB) is accomplished by utilizing data obtained during the CoMet 1.0 effort, which took place during May through June 2018. The researchers employed three-layered COSMO/MESSy simulations with a spatial scale of 2.8 km across the USCB. It was determined that MECO (3) was the most effective technique for observing methane plumes including their extensive patterns.

ZHANG et al. [36] introduced an environmental inversion framework that utilizes satellite imagery with high resolution for calculating sub regional releases of methane. This framework provides a reliable and accurate analytical instrument for assessing methane emissions across different areas. The researchers utilized contemporary satellite environmental inverse modeling to document the emissions of methane originating via the Permian Basin. The analysis revealed that the amounts of methane released generated by the Permian region for the period between May 2018 with March 2019 were estimated to total 2.7 ± 0.5 Tg.

Joost et al. [39] demonstrated novel aspects of the space-based Tropospheric Surveillance Instrument, which was launched in the USA in 2017. This TROPOMI gas columns were observed at their maximum levels in the most profound areas within the basin located in the Uintah Basin in Utah. Both New Mexico along with the Permian Basin in Texas have the highest levels of petroleum production. Methane-columns within these places showed maximum levels, which were also linked to NO2 columns based on in-situ aircraft observations.

Lena [40] conducted a projection of anticipated worldwide human-caused methane emissions from 2005 through 2030, considering the possibilities for technical abatement. The GAINS modeling framework is utilized to calculate the possibilities for reducing greenhouse gas emissions, as well as the associated costs, for all major sources of human-caused methane emissions across a total of 83 countries. Present-day methane production stands at approximately 323 million metric tons (Mt) in 2005 which is projected to rise to 414 million metric tons (Mt) by 2030. The estimated practical reduction potential for methane emissions in 2030 is 195 Mt, while there is significant uncertainty in the sources of these emissions.

Swolkień [43] examined the immediate release of CH4 emissions in the Upper Silesian Coal Basin in Poland due to the absence of a specific time frame. The methane levels in shafts varied between 0.05 and 0.4%. The significant methane emissions have been determined at Shaft VI (Mf II) ranging between 29 at 54 cubic meters per minute. The entire method was partitioned into 3 mining fronts (Mf), each consisting of two distinct intervals.

Karacan and Warwick [44] conducted a comparative evaluation to manage the utilization of abandoned mining methane and coal-field methane resources. The assessment was conducted on two adjacent sections of a longwall mining in Pennsylvania located in the Northern Appalachian Basin up to 2016. The study utilized a comprehensive geological dataset to quantify the emission of gas from shafts and generate values of GGV (Gas Gathering and Ventilation) for methane assets in abandoned mines. Another approach involves use publicly available algorithms to predict emissions that occur during mining operations.

Zheng et al. [45] provided a comprehensive analysis of the emissions related drainage methods used to remove coalbed methane (CBM) in the context of safety at the mine. This study provides a thorough examination of the following subjects: the release of methane within coal mines beneath the ground, methane generation, sources of emissions, movement and storage characteristics, calculation of emissions, and factors that influence emissions. Subsequently, three methane drainage techniques were implemented, considering the path of the borehole, in order to reduce methane emissions.

Tunnicliffe et al [46] examined the three primary components - anthropogenic activities, wetlands, and biomass burning - in Brazil from 2010 to 2018 using data from the Greenhouse Gases Observing Satellite (GOSAT). An aggregate of 33.6 ± 3.6 tera grams per year were released from 2010 through 2018. The human-caused emissions are estimated to be 19.0 ± 2.6 Tg/yr., the wetlands emissions are estimated to be 13.0 ± 1.9 Tg/yr., while the biomass combustion sources pollutants are estimated to be 1.7 ± 0.3 Tg/yr.

Meshkov et al. [47] managed the release of methane through using a sequence of deep mines containing gas with a highly profitable longwall within the Kuznetsk coal basin. Researchers successfully extracted methane gas through the mine of coal at a rate of as much as 250 m3/min as well as up to 60,000 tons per day.

Juganda and Aditya [48] have demonstrated that the proposed multi-sensor alert system provides more reliable and precise data on possible explosive methane levels near the shearer drumming, in comparison to the current monitoring method. The optimal spacing for ventilation intersects to achieve high effectiveness is 100 meters.

Precise forecasting is crucial for preventing coal explosion catastrophes. Mou and Liu [49] examined the sensitiveness of the forecast index for natural gas and coal outbursts at the Zhongling mining mine. The participants engaged in in-depth discussions on a number of subjects: the primary causes of natural gas and coal eruptions, the initial velocity indicator q for gas emissions during drilling, the sensitivity experiments for the weight indicator S of drilled cuttings, plus the gas dissociation index K1 for drilled cutting. The results indicated that the variables of gas concentration, ground stress, along with rock structure weren't having a significant impact on the values of S along with q. However, K1 exhibited clear variations in response to these three parameters.

Ke and Wang [50] collected the relevant data about coal-related gas accidents in China between 2003 through 2018 for analysis. Thanks to effective policies, the occurrence of coal mine disasters has significantly decreased. However, gas injuries have the highest proportion of fatalities compared to other mishaps. The author concluded that gas management rules have a significant influence on the frequency of gas injuries, and these recommendations are crucial for managing coal mine methane mishaps.

Gas bursts are one of the most common mishaps in coal mines. Tong et al. [51] reported that the workers' dangerous behavior led to a series of gas explosions in the past few years. This text discusses four categories of explosive casualties: gas prevention, breathing, fire extinguishing, electrical worker, and blast. Furthermore, a probabilistic threat assessment model has been used to analyze the risks caused by dangerous actions of various occupational groups. The ventilated working style is particularly perilous among the four categories.

As mine depth increases, gas eruption tragedies become more terrible, and preventing them becomes harder. Wang et al. [52] attempted to reduce the risk of gas eruptions within the Luling coalfield by suggesting the implementation of a safety measure that includes a suitable soft stone layer plus thick-and-deep mining seam. The present study in China presents a novel safety paradigm for the efficient utilization of both coal and gas assets found in deep coal-seams.

Yang et al. [53] examined the content and origin of gas emissions by utilizing gas emission forecasting in order to address the problem of gas contamination. The authors conducted research on extraction parameters, comprehensive oversight of gases in the workplace, and efficient utilization schemes for both high and low volume gases.

Imbiriba et al. [54] conducted calculations of methane gas production generated by the Aurá Landfill within PA-Brazil till 2015 using the IPCC's initial-order multiphase model. Its anticipated total amount of methane emissions is 484 gigagrams (Gg).

3.3. Prediction of Methane emission Using ANN - Literature Review

This This section discusses the paper's major point and shows that ANN offers the ability to better address methane pollution, however few articles have been published globally.

In 1993–2018, Tutak and Brondy [55] analyzed Polish coal mining methane emissions along with predicted them through 2025, according to ANN along with statistical approaches projected methane emissions. Additionally, identified methane drainage tendencies for the future.

To improve coal-site methane as well as emissions of gases prediction, Zeng and Li [56] used Nantun. After selecting grey forecasting model GM (1, 1), projected and real values were compared across various working face regions. Highest error between real and anticipated values being 2.41%; minimum being 0.07%.

To address data quality issues during 2017 through 2025, Ninget al. [57] proposed a rolling gray prediction system. Precision was improved by combining a novel algorithm with delayed rolling. Since it used nonlinear programming techniques to construct an adequate time response characteristic for anticipated, the adaptive grey modeling using the buffered-rolling technique is more adaptable than previous models.

Predicting coal mine emissions of methane can prevent methane accidents. Only grey concept plus neural network simulation can maintain reliable methane concentrations. A modified grey GM (1, 1) plus radial foundation function neural networks model by Yang et al. [58] solved the grey neural networking model restriction. The revised grey GM (1,1) simulation outperformed both the grey GM (1,1) simulation and the circular basis function network simulation.

Chen et al. [59] correctly forecasted gas emission utilizing twin grey theory algorithms (GM (1, 1) and extended regressed neural network that ignored non-linearity along with uncertainty. 13 parameters were entered into the model. This analysis uses every bit of gas collected from May 2007 through December 2008 by Qianjiaying Mining Area of Kailuan Mining Groups. The findings were accurate enough to predict coal mine methane disasters theoretically.

Using the BP neural network technique, Wu et al. [60] predicted coal accidents for Weicun Coal Mines in Jiaozuo City, China. It integrates an innovative GASA method with GA plus SA. The GASA-BP algorithm predicted coal and gas eruptions quickly and accurately in practice.

The changing, real-time, yet nonlinear grey GM (1, 1) emissions forecasting system by Yuan et al. [61] predicted gas emissions within Huainan area mines. Average relative variance was 6.14%, expected Index C score 0.48, P-value 0.90.

Using 3 input variables, Deng and Guo [62] trained 3 ANN frameworks in order to evaluate their BRM forecasting model. Increasing heat within the coal mines helps convert methane. Better neurons make a simulation of artificial neural networks more efficient, according to this article.

ANN steam-carbon di-oxide reformation of methane with nickel-based catalysis was used by Hwe and Chul [63]. Triple-layer forward feedback network using hyperbolic-tangent value was the ANN design. Maximizing R^2, minimizing MSE, and using 8 neurons enhance hidden neurons. These model's distinct variables are the rate of flow, feeding ratio, along with temperature.

Team Chowdhury [64]. Bangladesh utilized 1972–2019 agricultural information to anticipate methane along with carbon dioxide output using ANN models. The ANN model predicted Bangladeshi agricultural methane along with CO2 emissions with 95.33% reliability.

Karacan [16] believes operational, geological, and topographical variables make methane-emission prediction difficult. He predicted ventilator methane emission levels in ten states from 1985 until 2005 using PCA and ANN. The releases of methane were accurately predicted by the ANN algorithm.

ANNs were used to predict coal mine methane levels by Mathatho et al. [65]. 4ANN algorithms Study contrasted Levenberg-Marquardt, Scaled-Conjugate-Gradient, Gradient descent, alongside Resilient propagation backwards.

Levenberg Marquardt (LM) was the most precise. LM training is superior for root-mean-square errors and average square errors.

A mixed CNN-LSTM algorithm monitored and forecasted miners' health quality index (MHQI) to improve the coal mining safety and profitability by Dey et al. [66]. With LSTM and CNN simulations, the projected mean square error (MSE) was smaller than 0.0009 with 0.0025 for MHQI as well as 0.0011 as well as 0.0033 with methane.

The study by Stamenković et al. [67] utilized artificial neural networks (ANN) to create a nationwide methane emission prediction model. Two ANNs are used: generalized regress along with back propagation. The automatic neural network (ANN) model outperformed the MLR.

Table 6 Summary of Top Publications

Publication Name	**Number of Research Paper**
International Journal of Coal Geology	4
IEEE Access	4
Applied Sciences	3
International Journal of Mining Science and Technology	3
International Journal of Greenhouse Gas Control	2
The Journal of Engineering	2
Process Safety and Environmental Protection	2
Scientific Geo Conference	2
International Journal of Environmental Research and Public Health	2
Journal of Nanoscience and Nanotechnology	1
Natural Resources Research	3
IOP Conference Series	3
Journal of Physics	1
Arabian Journal of Geosciences	1
CIM Journal	1
Journal of Cleaner Production	1
E3S Web of Conferences	1
European University Institute	1
Journal of the Serbian Chemical Society	1
Others	9

4. Discussion

Among 46 research papers, more than half indicate methane emission is increasing than previous studies. Other useful results which we got from research papers is that abandoned mines are playing a major role in methane emissions along with agriculture. The studies have concluded that if you stop producing coal, that doesn't indicate that methane will halt being emitted from underground.

The aim of this systematic review was to investigate the methane emissions sources, their prediction, and the role of ANN in forecasting accurate methane emissions (RQ1, RQ2 and RQ3). Several authors have discovered that active coals, abandoned coals and agriculture (such as enteric fermentation, manure supervision, residue burning and rice cultivation) are the main resources of methane emissions. Later further studies uncovered the depth-specific emission factors to estimate methane emissions from coal mining. It is not easy to control the emission of the methane. Even coal mine is closed properly but studies showed that atmosphere can experience the methane-emissions from abandoned coal mines. One more interesting fact which was discovered during the research is the waste of methane gas and energy [17]. A few coal industries use the methane as a power generation fuel otherwise it is extracted by mine ventilation. Basically, we are wasting sustainable and affordable energy every day. Moreover, almost every paper has mentioned the risk associated with methane occurrence and a threat to the exploitation process during mining production. It is a highly flammable gas, and it has a greater chance of combustion or explosion. We have mentioned some past incidents in the start of this study. Methane also causes air pollution as it is one of the greenhouse gases that donate to temperature changes.

Many authors have concluded in their studies that accurate prediction is the only possible solution to get rid of major causalities inside the coal mine. Different technologies are used to analyze of both the present and the future situations of methane-emissions from coal seams. Major studied have found the ANN is the most predictive tool with high accuracy. Some studies also compared both linear and non-linear statistical models with the ANN model using the testing data and ANN performed well due to its extremely non-linear nature [16]. A developed ANN model not only can predict the accurate CH4 but also can be used in sustainable development strategies and environmental management policies.

Another major situation needs to be discussed "how to stop the methane emissions from coal mine? We have seen in our studies some authors suggested if coal production reduce, then emissions from active mines would decrease. But it is hard to achieve as the USA is decreasing its coal production but in Asia every year the coal production is increasing specially in China. The best solution is to discover the technology to reuse the emitted methane in proper way to find economic potential of this energy resource without any mishap.

Methane emissions can badly impact the protection of underground coal miners. The disclosure of methane may depict symptoms such as wheezing, asphyxia, coughing, shortness of breath, or burning of the mouth. Duda and Valverde [69] presented a hazard investigation of the methane hazard happening at the final stage of coal production in an underground mine in Poland. They discussed the flooding procedure and how it impacts the ranking of gas emissions from modifications in methane gas concentration, goofs, and differences in the volume of voids. Coal mine unexpected and undesirable incidents negatively impact national progress and welfare [70]. It's a big challenge for the coal industry to ensure precautions and inspections underground to gain the trust of workers. To recover the mood and motivation levels of workers, continuously monitoring is significant to mitigate risk.

5. Conclusion

Most of the included studies discussed the current status of the methane emissions from different regions and indicate that the safety and management of coal mines still do not enter a stable period. We have revealed different ANN modeling techniques for methane emission and also compared the accuracy in the review part. We saw that mixing the ANN with other technology can give better accuracy. For example, function neural network with modified grey GM (1,1) model performed better. This review showed that the relevant theoretical framework of methane emission, prediction of methane using different technology, and technical support are slowly improving. However, ANN is the best so far to ensure methane prediction. The methane emission is not the only problem for mine workers but also a big challenge for managing the energy crisis. The lack of technology in predicting has caused many causalities so far. Thousands of people have died so far due to inexperienced tools and types of equipment. Moreover, an in-depth emergency reaction plan and continuous training are essential to mitigate the risk of a crisis.

In the future, the ANN technology for methane accurate prediction will restore worker's trust through the integration of safety ethics. This study still has some constraints that should be noted. This paper refers to only last four years papers which is not enough to clearly predict the future of coal mining. Moreover, workers trust and risk factors in coal safety and energy crisis can be discussed in more details for future studies. Moreover, we can focus on one country to better understand the current status of the methane emission in future work.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors (Sundas Matloob *, Li Yang, Sumaiya Bashiru, Ikram Ullah, Marcel Merimee, Iqra Yamin) declare no conflicts of interest regarding the publication of this paper.

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