

# OCCUPATIONAL HEALTH AND SAFETY IN INDIAN COAL MINING - TRENDS AND POLICY IMPLICATIONS

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## Abstract

*Coal mining remains a high-risk occupation in India despite sustained regulatory and technological interventions. This study analyses the long-term trends in fatal and serious accidents in Indian coal mines from 1997 to 2022 using secondary data from the official sources of the Government of India. Descriptive statistics combined with the Mann-Kendall trend test and Sen's slope estimator for the assessment of the trend direction and magnitude. The results indicate a statistically significant and consistent decline in both fatal and serious accidents, with a more pronounced reduction in the rate of serious accidents. However, the continued occurrence of accidents highlights persistent occupational safety risks. The findings emphasize the need for continued regulatory enforcement, systematic monitoring and preventive safety strategies for strengthening mining safety performance.*

## Keywords:

*Occupational Health and Safety, Coal Mining Safety, Fatal and Serious Accidents, Safety*

## 1. INTRODUCTION

Mining is widely recognized as high-risk industrial activity, as workers operate in environments marled by unstable geological conditions, confined spaces and the extensive use of heavy machinery. In India, coal mining remains a cornerstone of energy production and industrial development, employing a large section of workforce across the diverse terrains (Lahiri-Dutt,[20]). The diverse worlds of coal in India: Energising the nation, energising livelihoods. *Energy Policy*, 99, 203-213. Despite notable progress in safety regulation and monitoring system, fatal and serious accidents continue to occur, underscoring persistent safety concern within the sector. Over the years, several policy reforms and technological interventions have been introduced for the improvement of occupational safety in Indian coal mines. However, the extent to which these measures have translated into sustained reductions in accidents requires careful monitoring. Studying long term trends of accident provides valuable insights into safety performance, highlighting the areas where risks remain high and helps assess the effectiveness of existing safety strategies (Sahu and Mishra,[23]). In this context, the present study focuses on the analysis of fatal and serious accidents in Indian coal mines over a period of twenty-six years to understand evolving patterns of accident and the overall progress of mine safety management in India.

### 1.1 LEGAL FRAMEWORK

Mine safety in India is governed by a structured legal framework aimed at protecting worker's health and lives. The Mines Act, 1952, serves as the principal legislation, defining safety obligations, inspections and accident reporting. The Coal

Mines Regulations, 2017, provide detailed operational standards for coal mines. These are supported by the Mines Rules, 1955, and safety circulars issued by the Directorate General of Mines Safety.

### 1.2 INSTITUTIONAL FRAMEWORK

The institutional responsibility for mine safety in India lies primarily with the Directorate General of Mines Safety (DGMS) under the Ministry of Labour and Employment. DGMS enforces mining safety laws through inspections, accident investigations and technical guidance. Ministry of Coal supports policy formulation safety improvement and technical modernization initiatives.

### 1.3 CONTEXT OF THE STUDY

Coal mining sector in India is vital for energy security, but it remains associated with high occupational risk. Although the safety regulations and monitoring systems have improved over time, fatal and serious accidents continue to occur. Against this backdrop, this study present examines long-term trend accidental data using statistical trend analysis to evaluate changes in accident patterns and assess the effectiveness of mine safety interventions.

## 2. LITERATURE REVIEW

Occupational health and safety (OHS) issues in the mining industry have attracted considerable global attention due to the inherently hazardous nature of the sector. For the purpose of identifying research gap, following literatures have been reviewed.

Saha [21] looked at occupational health within India's industrial landscape and found a persistent gap between policy creation and execution, especially in sectors like mining, where informal and contract labor are prevalent. Alrawad et al. [4] took a psychometric approach to understand miners' views on workplace and environmental risks. They discovered that education level, work experience, and commitment to safety from management heavily influence risk perception. In terms of psychosocial factors, Fagnoli et al. [10] had recommended incorporating knowledge management into OHS systems, arguing that sharing information helps with anticipating hazards and following safety rules. From a management angle, Marimuthu et al. [15] used the SWARA method to highlight key OHS components in mining. They found that training, supervision, and risk assessment are crucial for safety outcomes. Extending this topic, Ali et al. [2] studied OHS reporting by manufacturing firms in Pakistan. They found low reporting quality in lower-middle-income countries, reflecting systemic neglect of worker safety. Neelakanti and Sriramula [12] studied coal mine workers in South India. They revealed high rates of respiratory and musculoskeletal

issues due to poor ventilation, frequent dust exposure, and lack of protective measures. Jackson and Quinlan [17] further analyzed the link between contract labor and safety results in mining. They noted that outsourcing and unstable employment often lower safety standards and accountability. From a regional perspective in India, Fagnoli et al. [1] suggested a Hazard Function Deployment model based on Quality Function Deployment principles to better assess safety at the task level. This method is applicable to mining settings. Amponsah-Tawiah and Mensah [3] studied how OHS practices relate to organizational commitment. They concluded that good safety management boosts employee loyalty and job satisfaction. Regarding technology, Yang et al. [14] showed that using information technology, such as the Internet of Things (IoT) and data analytics, could improve safety monitoring and risk assessment. They advocated for a shift toward preventive safety cultures.

The research of Bhattacharya and Bhattacharya [18] highlights the decreasing rate of accidents in coal mines in India. The research also revealed the persistence of occupational health and safety risks in Indian coal mining, despite regulatory reforms and improvement in safety surveillance system. De Cieri and Lazarova [8] reviewed OHS research related to international workers. They emphasized the need for consistent safety standards and a complete approach to worker well-being in a more global labor market. Asad et al. [6] highlighted the role of transformational leadership in connecting safety culture to performance in small and medium-sized enterprises, offering insights important for mining, where leadership shapes safety priorities.

Thus, these studies indicate that despite progress in occupational safety, issues like unstable labor relations, limited use of technology, weak safety cultures, and a lack of psychological support still impede safety outcomes in the mining industry.

### 3. RESEARCH GAP

Despite extensive study on occupational health and safety in mining, long-term statistical analysis of fatal and serious trends in Indian coal mines remains limited. Existing studies rarely quantify trend direction, magnitude and stability using robust non-parametric methods, restricting evidence-based evaluation of sustained safety regulations and interventions over the period of study.

### 4. OBJECTIVES OF THE STUDY

The present study is undertaken with the following specific research objectives:

- To understand how fatal and serious accident patterns in Indian coal mines have evolved over time.
- To examine the extent and year-to-year variation of occupational accidents.
- To measure the magnitude of changes over time period of the study.

## 5. RESEARCH METHODOLOGY

### 5.1 RESEARCH DESIGN

This study uses a quantitative and longitudinal research design to analyze changes in fatal and serious accidents in Indian coal mines from 1997 to 2022. The analysis is based on secondary data collected from official sources of DGMS, NIMH and NIOH. Initially, descriptive statistics have been used for the analysis of the pattern, spread and variation in accident occurrence over the period of study. To examine whether accidents followed a consistent increasing or decreasing trend, the Mann- Kendall trend test has been applied at a 5 % level of significance. Sen's slope estimator was then used for the measurement of the rate of change, providing an insight into the magnitude of safety improvements over the study period.

### 5.2 DATA SOURCES

The study exclusively utilizes secondary data sources, ensuring methodological transparency and replicability. The following secondary data sources have been utilized for this research:

1. SANKET statistical series (2016 – 2022) published by the Directorate General of Mines Safety (DGMS).
2. Reports published by the Ministry of Coal and Press Information Bureau (PIB).
3. Publications from the National Institute of Miners Health (NIMH) and the National Institute of Occupational Health (NIOH).

### 5.3 ANALYTICAL TOOLS

The quantitative research incorporates a comprehensive evaluation of the accident data and work-related outcomes by employing multi-faceted statistical approaches. The following quantitative methods have been applied for the identification of the patterns, trends and magnitude of the accidents in Indian coal mines.

- **Descriptive Analysis:** Basic descriptive statistics (mean, median, minimum, maximum, and standard deviation) were computed to provide a summary of fatal and serious accidents.
- **Mann- Kendall Trend Test:** This non-parametric test is used to determine whether a time series has a monotonic upward or downward trend. A very high value of Mann-Kendall Statistic is an indicator of an increasing trend and a very low negative value indicated a decreasing trend.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(X_j - X_k) \quad (1)$$

where,  $X_j$  and  $X_k$  are the annual values in years  $j$  and  $k$ ,  $j > k$  respectively,  $X_k$  represents the data point at time  $k$ . The value of  $\text{sign}(x_j - x_k)$  is computed as the number follows:

$$\text{sign}(X_j - X_k) = \begin{cases} 1, & \text{if } X_j - X_k > 0 \\ 0, & \text{if } X_j - X_k = 0 \\ -1, & \text{if } X_j - X_k < 0 \end{cases} \quad (2)$$

To measure the strength and direction of the trend, Kendall's Tau ( $\tau$ ) coefficient is computed as:

$$\tau = \frac{S}{\frac{n(n-1)}{2}} \tag{3}$$

- **Sen's Slope Estimation:** This is a non-parametric method used to determine the magnitude of a monotonic trend in time-series data. The estimator was applied separately to fatal accidents and serious accidents for the period 1997–2022.

$$Q_i = \frac{X_j - X_i}{j - i} \tag{3}$$

for all  $j > i$ . where  $X_j$  and  $X_i$  are accident counts at time  $j$  and  $i$  respectively. Since  $N=325$  (odd), the median is the 163rd slope.

- **Software:** Python 3.12.8 has been used for data analysis and visualization. Microsoft Office 365 (LTSC Professional Plus, 2024) is used for documentation and tabulation of collected data.

## 6. RESULTS AND DISCUSSION

### 6.1 DESCRIPTIVE ANALYSIS

The descriptive analysis presents an overview of accident pattern in Indian mines over the study period i.e.; 1997 – 2022. By examining measures such as mean, median, maximum, minimum values of fatal and serious accidents, the overall magnitude of occupational risk and its variation over the time of study can be understood. The calculated standard deviations further reflect the extent of year-to-year fluctuations in accident occurrence. This analysis helps to identify broader trends and deviations in safety performance across different years.

The descriptive statistics (Table.1) indicates a steady reduction in both fatal and serious accidents in Indian coal mining from 1997 to 2022. Serious accidents remain much more frequent and display wider year to year variation, suggesting that non-fatal safety risks were more unstable over the period of study. According to Fig.1., higher fluctuations during the early 2000s point to weaker safety control during this phase, whereas the steady decline after 2010 reflects gradual improvements in safety management and regulatory enforcement. Fatal accidents, on the other hand, shows slower variability indicating a more controlled reduction in extreme risk outcomes. The observed patterns provide a strong basis for applying formal trend analysis to verify the direction and strength of safety improvements over time

Table 1. Descriptive statistics (N = 26)

Parameters	Fatal Accident	Serious Accident
Mean	79	525
Median	79	535
Minimum	24	117
Maximum	143	1106
Standard deviation	28	256

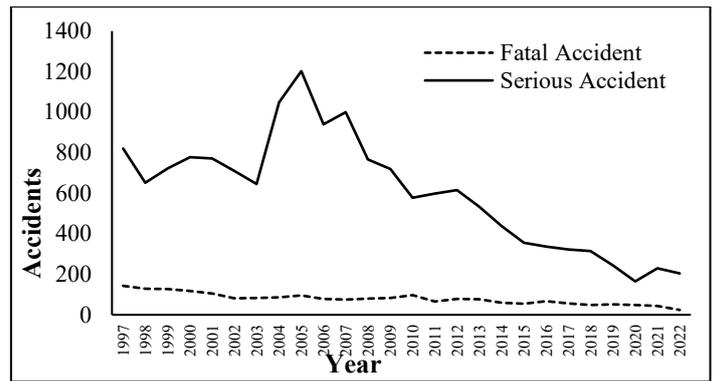


Fig.1. Trend of Fatal and Serious Accidents in Coal Mining (1997 – 2022) (Source: SANKET REPORT [2016-2022], <https://www.dgms.gov.in>)

### 6.2 MONOTONIC TREND ANALYSIS OF MINING ACCIDENTS

For the purpose of statistical examination of the presence of monotonic trends in coal mining accidents over the period of study, the Mann- Kendall trend test has been conducted at 5 percent level of significance. The results of the Mann- Kendall test is presented in Table.2.

Table.2. Mann- Kendall Trend Test

Accident Category	Kendall's $\tau$	Z-value	p-value	Trend Direction
Fatal Accidents	-0.814	< -1.96	< 0.001	Significant decreasing
Serious Accidents	-0.649	< -1.96	< 0.001	Significant decreasing

The Mann-Kendall trend test in Table.2 indicates a strong trend in both fatal and serious mining accidents over the period of study. The negative value of Kendall's tau values indicate a consistent declining trend, while very low p-values implies that the improvement is not due to chance. Therefore, the findings showcases a significant progress in mine safety, although the persistence of the accidents indicates that continued vigilance and preventive efforts remain important.

### 6.3 MAGNITUDE OF ACCIDENT TRENDS

For the measurement of the magnitude of changes over time, Sen's slope estimator is used. This method provides a robust estimate of the median rate of change in accident occurrence per year. The estimated slopes of fatal and serious accidents are presented in Table.3.

Table.3. Sen's Slope Estimation

Accident Category	Sen's Slope (Q)	Trend Interpretation
Fatal Accidents	-3.4	Moderate annual decline
Serious Accidents	-24.9	Steep annual decline

The result in Table.3 indicates a sustained decline in both fatal and serious accidents in Indian coal mines during 1997 - 2022. Fatal accidents show a moderate annual reduction, with an

average decrease of around three to four cases per year, reflecting gradual and consistent improvement in controlling several safety risks. In contrast, serious accidents indicate a steeper annual decline of nearly twenty-five cases, showing a reducing non-fatal but high frequency incidents. The larger magnitude of decline in serious accidents highlights the effectiveness of preventive measures, operational monitoring and safety training. In brief, the Sen's slope results complement the Mann-Kendall findings and confirm both the strength and direction of the long-term improvements in the performance of mines safety.

## 7. CONCLUSION

This study examined long-term trends in fatal and serious accidents in Indian coal mines during 1997-2022 using descriptive statistics, the Mann-Kendall trend test and Sen's slope estimation. The result clearly indicates a consistent and statistically significant decline in both fatal and serious accidents over 1997-2022. Descriptive analysis highlights not only a reduction in the number of accidents but also lower year-to-year fluctuations in recent years, suggesting greater stability in mine safety conditions. The Mann-Kendall test confirms the presence of a strong monotonic downward trend, while Sen's slope estimates provide quantitative evidence of the rate of decline, showing a moderate annual decrease in fatal accidents and a much sharper reduction in serious accidents. Nevertheless, the continued occurrence of accidents, even at lower levels, highlights that safety risk persists and requires ongoing attention. These results underline the importance of maintaining preventive safety strategies including behavioral safety initiatives, regular inspections and improved monitoring systems. From a policy perspective, the observed trends demonstrate that a sustained regulatory commitment would yield measurable safety gains in high-risk segments. Future research can be executed by extending the present analysis by incorporating regional data, workforce characteristics and technological factors by applying advanced analytical approaches for the better understanding of the accident causation and support more effective mine safety interventions.

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