

Analysis and Forecast of Mining Fatalities in Cherat Coal Field, Pakistan

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Abstract: Mineral exploitation contributes to the economic growth of developing countries. Managing mineral production brought a more disturbing environment linked to workers' casualties due to scarcities in the safety management system. One of the barriers to attaining an adequate safety management system is the unavailability of future information relating to accidents causing fatalities. Policymakers always try to manage the safety system after each accident. Therefore, a precise forecast of the number of workers fatalities can provide significant observation to strengthen the safety management system. This study involves forecasting the number of mining workers fatalities in Cherat coal mines by using Auto-Regressive Integrating Moving Average Method (ARIMA) model. Workers' fatalities information was collected over the period of 1994 to 2018 from Mine Workers Federation, Inspectorate of Mines and Minerals and company records to evaluate the long-term forecast. Various diagnostic tests were used to obtain an optimistic model. The results show that ARIMA (0, 1, 2) was the most appropriate model for workers fatalities. Based on this model, casualties from 2019 to 2025 have been forecasted. The results suggest that policymakers should take systematic consideration by evaluating possible risks associated with an increased number of fatalities and develop a safe and effective working platform.

Keywords: Mining, fatalities, coalfield, Cherat, safety.

Introduction

Pakistan has huge mineral reserves including coal, rock salt, dimension stones, industrial and metallic minerals and precious stones (Malkani and Mahmood 2016, Malkani and Mahmood 2017, Malkani et al., 2017). Unfortunately, revenue from mineral exploitation does not match with its potential (Shah et al., 2019, Jiskani et al. 2020, Shah et al. 2020). The country has started an open-pit coal mine with an estimated 7.8 million tonnes annual production from block-1. Nowadays, minerals are mainly exploited through small-scale mining in Pakistan (Jiskani et al. 2019, Shah et al. 2020). However, this sector is still ignored regarding safety that is resulting in workers casualties. Therefore, it is unavoidable to conduct effective research to improve the workplace safety and diminish the probability of mining fatalities (Jiskani et al. 2019, Jiskani et al. 2020). During mine management, the safety officer should acquire accurate forecasting results to appraise future safety to reduce the number of casualties. Precise forecasting not only reduces the number of casualties but also minimizes economic losses.

The most frequently referred factors responsible for worker casualties include roof fall, the suffocation of noxious gases, electrocution, explosion, mine machinery and oxygen deficiency (Jiskani et al. 2019, Jiskani et al. 2020, Shahani et al. 2020, Zhang et al. 2020). These factors are categorized into proximal causes, workplace causes and systematic factors.

Accidents caused by human errors are considered as proximal causes, while workplace factors address errors and violations generating an unsafe working environment. The systematic factors appraise how management contributes to violation or error (Bonsu et al., 2017). Due to the dynamic nature of safety management in the mining sector, it is impossible to describe it with a simple data model.

Various statistical modeling techniques are widely used to predict the upcoming situation (Sarkar et al., 2019, Xie et al., 2019, Wang et al., 2020, Xu and Xu, 2020). Time series forecasting is an extensively used technique to predict accidents in civil aviation, road, factory and mining sectors. ARIMA model was first presented by Box and Jenkins in 1976 to forecast time series data. ARIMA model uses original time series data as a random series to forecast (Box et al., 2015). Once a precise model is selected, it may generate a forecast of future values concerning the actual time series. Many researchers predicted future accidents and casualties using the ARIMA model. Kher and Yerpude (2016) used various time series forecasting techniques to predict Indian coal mine accidents data. Al-Zyood (2017) employed the ARIMA model to forecast car accidents in Saudi Arabia. Ghédira et al. (2018) appraise the strategy relating to a safe environment in Tunisia using the ARIMA model. Rajaprasad (2018) predicted the number of accidents in Indian factories using the time series forecasting ARIMA model and identified that number of accidents can be increased be in the future. Consequently,

management should be aware of the risky situation. Li (2019) developed a time series ARIMA model according to mutation and Mann-Kendall trend analysis to predict the number of accidents and fatalities in civil aviation accidents in the world. Aforementioned, researchers used time series analysis to forecast accidents and fatalities to produce potential weightage to factors accountable for causalities. Earlier workers revealed that the resulting accidents and fatalities might increase or decrease, but alternatively, provided a better overview of management to improve the safety management system. For this purpose, this study was conducted to describe the application of the forecasting model to minimize the number of fatalities and economic losses in Cherat coalfield. The time series ARIMA model was used to predict the future values of mining workers' causalities.

Materials and Methods

Mining fatalities data from 1994 to 2018 were collected from the Inspectorate of Mines and Minerals, Khyber Pakhtunkhwa, Pakistan Mine Workers Federation and company records. Such data also comprises accountable factors for mining fatalities over the year 1994 to 2018, which include roof fall, the suffocation of noxious gases, electrocution, firedamp explosion, mine machinery and oxygen deficiency. The time series analysis model is the best technique to describe the relationship between the parameters' past and future values (Shumway and Stoffer, 2011). The output of the ARIMA model is more consequential in the eliminations of the explanatory model, which relates the explanatory variable with the forecasted variable. In this study, a time series ARIMA model is employed to forecast the number of causalities in Cherat coalfield.

The ARIMA model is a useful time series analysis technique for evaluating the longitudinal data with correlation among associated observations. This time series technique contains significant statistical properties that make it suitable for the analysis of linear data. For the stationary data, the ARIMA model is a linear function of lags of past observations and the lags of forecasted errors. A simple equation can represent the ARIMA model;

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \dots + \alpha_p y_{t-p} + \varepsilon - \beta_1 \varepsilon_{t-1} - \dots - \beta_q \varepsilon_{t-q} \quad (1)$$

Where y_t denote actual observations values while ε_t expressing the random error (future values) at period t , accordingly α_i ($i= 1, 2, 3, \dots, p$) and β_i ($i= 1, 2, 3, \dots, q$) are the model parameters; p and q are integers that identify the order of the model. Furthermore, the random error is uniformly distributed over the mean with zero and constant variance σ^2 . The order of the ARIMA model can be defined by two components, by evaluating the behavior of time series,

referred to as autoregressive (AR) and moving average (MA).

Results and Discussion

This study investigated the changing trend in the mining fatalities in Cherat coalfield, Pakistan. The number of fatalities exhibits fluctuation over the years (Fig. 11). From 1994 to 2018 the number of fatalities is inconsistent, firstly it decreases, then shows an increase, while at last, it goes down. The decrease in fatalities indicated that mining activities in Cherat coalfield are declining. The R-square value for the trend is 3.58, which indicates that statistically, it is highly significant.

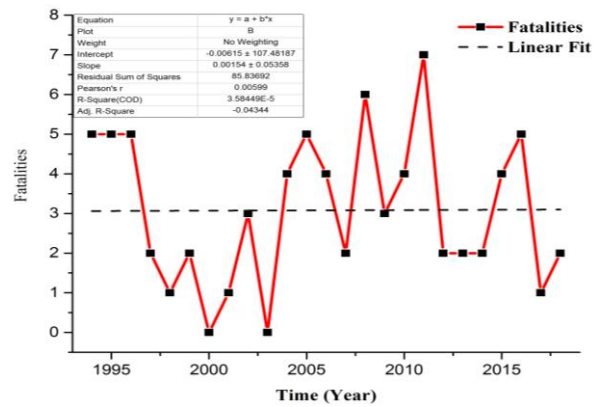


Fig. 1 Trend change in the number of fatalities in Cherat coalfield from 1994 to 2018.

The data revealed that the number of workers fatalities is higher for roof fall, followed by suffocation of noxious gases (Fig. 2). In the years 2008 and 2010 the number of fatalities caused by noxious gases compared to roof fall. Following the law of time change, each cause of workers fatalities from 1994 to 2018, the mining workers fatality increases and decreases inconsistently, excluding factors of electrocution, explosive and mine machinery.

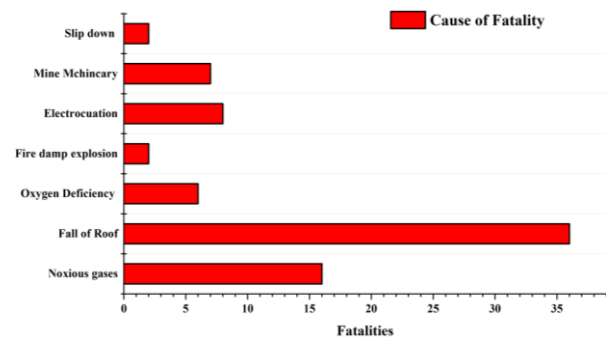


Fig. 2 Mine workers fatalities caused by accidents.

For time series analysis, the ARIMA model can be used for data following a linear pattern. Usually ARIMA model required a stationary data set, although non-stationary data are pretreated to be stationary using differencing. The data plot indicates that the series is non-stationary (Figs. 3, 4, 5). The step involves logarithmic transformation to eliminate the

heteroskedasticity in time series, while in the second first-order difference is applied to transfer the time series into stationary series. The autocorrelation function (ACF) and partial autocorrelation function (PACF) plots are also used to acquire the values of ARIMA parameters p, q and d.

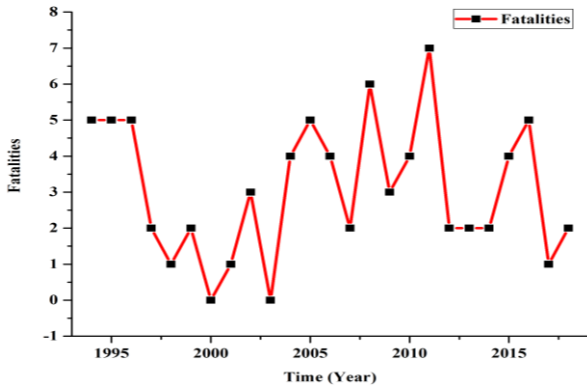


Fig. 3 Number of mine workers fatalities over time.

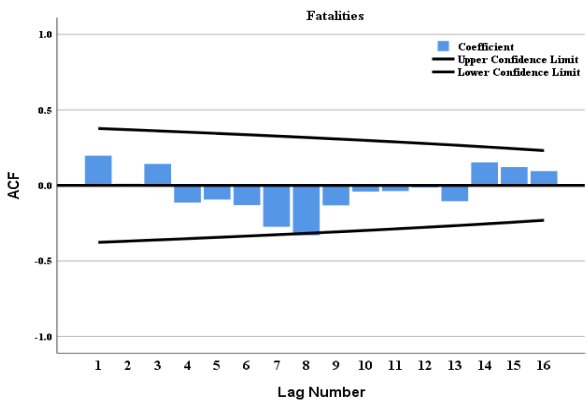


Fig. 4 The Autocorrelation plot for the number of fatalities.

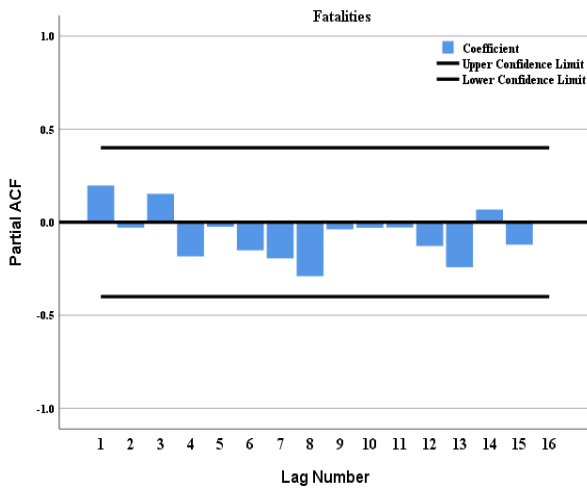


Fig. 5 Partial autocorrelation plot for the number of fatalities.

In this research, root means square error (RMSE), mean absolute error (MAE), Akaike information criteria (AIC) and Hannan Quinn criteria (HQC) will be used to select the appropriate model. According to this process, the model with the lowest values for all these parameters will be selected. Five ARIMA

models are entertained and the model with the least values is adopted (Table 1).

Table 1: Parameters comparison for fitted ARIMA model.

ARIMA model	RMSE	MAE	AIC	HQC
ARIMA(0,1,2)	1.92509	1.59909	1.46994	1.49699
ARIMA(0,1,1)	2.02413	1.77334	1.49028	1.50381
ARIMA(1,1,1)	1.95574	1.54274	1.50154	1.52859
ARIMA(1,1,2)	1.94172	1.62105	1.56715	1.60772
ARIMA(2,1,0)	2.03888	1.74722	1.58481	1.61185

By comparison of the parameters, it is revealed that ARIMA (0,1,2) is the most appropriate model with RMSE= 1.92, MAE=1.6, AIC=146 and HQC=1.49. The resultant model can be used to predict the number of fatalities in Cherat coal mines. Furthermore, the ARIMA (0,1,2) model is used to fit the number of mine workers fatalities at Cherat coalfield from 1994 to 2018. The actual values, fitted values, forecasted values and residual are given in Table 2. In this study, the number of fatalities is forecasted from 2019 to 2025 using the chosen model according to the previously collected fatalities data from 1994 to 2018. After that, predicted values are joined to the existing time series to acquire a model acclimated to a new time series, to predict the worker's fatalities from 2019 to 2025 (Fig. 6).

Table 2. The actual and predicted values of the number of fatalities.

Time (Year)	Actual values	Forecasting values	Residual
2015	4	2.81	-1.40
2016	5	3.47	-.73
2017	1	3.65	-.55
2018	2	2.37	-1.83
2019		2.97	
2020		3.06	
2021		3.06	
2022		3.06	
2023		3.06	
2024		3.06	
2025		3.05	

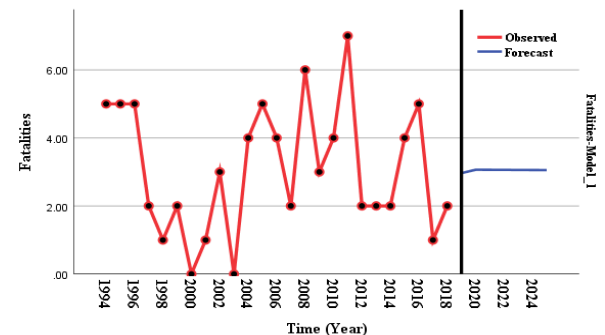


Fig. 6 Time sequence plot for the observed and forecasted number of workers fatalities.

Conclusion

The present study concludes statistical analysis and building a time series ARIMA model to forecast the

number of causalities in Cherat coal mines, Pakistan over the year 1994 to 2018. The statistical analysis unearths that the real causes behind mining workers fatalities are due to inadequate mine support and ventilation system, which indicates that mining safety in Pakistan is at high risk. Consequently, there is an urgent need for an effective safety management system to minimize the number of workers' causalities. The statistics revealed that there is intensive professional unskillfulness relating to the prior evaluation of safety risk. There is an imperative need to build a time series forecasting model to appraise the future safety condition. The forecasted results show the increase in workers fatalities in the Cherat coal field over the year 2019 to 2025. The results can also be depicted as the parameters responsible for workers fatalities, influenced by the application of various strategies to strengthen the safety management system. Therefore, considering the safety risk by accurate forecasting can ensure early identification for the hidden hazard and provide a safe and effective working platform.

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