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Comparative Analysis of Coal Miner's Fatalities by Fuzzy Logic

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Abstract

In this work, we employ the fuzzy logic technique to achieve and present, for the first time, a proper analysis of the actual intensity of the increase in the coal miners' fatality rates in Pakistan from 2010 to 2018, compared with China and India, with an objective to minimize the impact of incidents on the miners' fatalities. The average and yearwise fatality rates in Pakistan, compared with China and India, are used for the fuzzy logic technique in order to calculate the actual degree of flexibility for the surging fatalities. The findings show that both the average (2010-2018) and yearwise fatality rates in 2011, 2015, and 2018 are 2.44, 1.74, and 1.6, respectively. In the fuzzy logic technique, the variables whose membership function (μ) values are ≥ 1 represent the absolute truth. The membership function values for the years 2011, 2015, and 2018 are alarmingly high for the fatalities of coal miners. Similarly, except for 2014 and 2010, where 0 represents the absolute falseness, the results for the remaining years indicate high fatality rates with a flexibility (or small extent) of its corresponding membership function (μ) values such as 0.623, 0.739, 0.219, 0.173 and 0.115, and 0.714, 0.24, 0.01, 0.324 and 0.317 using the average and yearwise analysis, respectively, compared with China. Likewise, the fuzzy logic membership function (μ) values compared with India in the remaining years are 0.704, 0.795, 0.386, 0.159, 0.352 and 0.306, and 0.675, 0.795, 0.386, 0.186, 0.321 and 0.322, respectively. The proposed fuzzy logic analysis has been founded based on the theory of fuzzy sets to properly identify the miners' fatalities, and also to suggest the implementation of appropriate recommendations to reduce the fatalities in the coal mines in Pakistan.

1. Introduction

Mining is one of the oldest industries [1-3], and it is considered as a dangerous job among all occupations because of its insecure and hazardous working conditions [4-6]. Accidents have the potential to instigate damage or injury, and are the sources of threat [7]. Ensuring the coal mining industry's safe production was founded upon 'coal-mine safety regulations' [8]. Safety is the primary task in the underground coal mining, particularly in Pakistan, China, and India, especially due to the surging fatality rates [9-12]. A safe coal production is closely linked to a country's economic and community development [13-14]. The safety production level in Pakistan has decreased continuously due to the laxity of safety supervision and practical actions. The mining sector particularly requires effective safety management policies to control the increased rate of fatal accidents.

Boal [15] has analyzed the problem of per piece payment model related to safety problems. He calculated the speed or intensity of coal mine workers, and thus indicated that the prevention of accidents by taking into consideration different safety procedures and precautions reduces the production efficiency and thus becomes expensive for the coal miners. Wang *et al.* [15] have studied the fatal accidents in the coal mines of China from

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2006 to 2010, finding that gas explosion has been the most significant cause of the coal mine-related deaths during the period.

Based on the previous research works, most of the fatalities in underground coal mines during the coal production operations in Pakistan are the consequence of various types of fatal accidents, as shown in Figure 1 [17-18]. Various fatal accidents caused due to the shortage of safety measures have been reported. On 20th March 2011, 52 people died due to a mine collapse in the Sor-Range area in the province of Balochistan; the mine was run by the Pakistan Mineral Development Corporation; all the dead miners were aged between 18 and 25 years. On 9th February 2015, another fatal accident was reported, where a total of 19 people were killed by a mine collapse in a mine in Khyber Pakhtunkhwa. Likewise, on 13th August 2018, 18 deaths were reported on account of a mine collapse in Dukki, Balochistan. These major accidents resulted in enormous financial costs and fatalities. Therefore, such a working nature of coal mines appears to be undefined; as a result, it is essential to launch effective safety measures to hinder the effect of fatalities or fatal accidents [19].

Ghasemi and Ataei [20] have applied the fuzzy logic technique to predict the roof fall rate in coal mines. Their results indicated that 'fuzzy model' was quite suitable for predicting the rate of 'roof fall'. Mohseni and Ataei [21], using the time series modeling, have predicted the "Tazareh coal mine" risks. The results obtained indicated a decrease in both the average number of accidents and the average number of work days. Ghasemi *et al*. [22] have presented a new method to evaluate the RFS (roof fall susceptibility) by employing the fuzzy method. They applied their new methodology to the 'Tabas Central Mine'. As per their findings, this methodology is operational and proficient in evaluating RFS. Ataei *et al*. [23], using the fuzzy logic membership operations, have developed rules based on the fuzzy models to consider the main goal of 'mechanization of mining'. 'Takht coal seams' were used as an example case. As per their findings, there existed a huge scope for the 'mechanization' of most of the 'Takht coal seams mines'. Sereshki *et al*. [24] have improved the 'RMR (rock mass classification system is a geo-mechanics classification)' methodology by the application of the fuzzy logic technique to present a better manner rock mass depiction. Daftaribesheli *et al*. [25] have described the employment of the 'fuzzy set theory' in the SMR cataloguing by including the 'fuzzy sets'. Khalokakaie *et al*. [26] have elaborated the fuzzy cataloguing method for assessing the rock mass resilience. Hosseini *et al*. [27] have provided a comparison of the coal mine fatalities in Pakistan with the fatalities in the coal mines of China and India.

This research work provides a comparative analysis of the fatalities in the coal mines in Pakistan from 2010 to 2018 in terms of its increasing rates, compared with China and India. In this work, we used the fuzzy logic technique to achieve a proper understanding of the actual intensity of the surging fatality rates still rarely employed and not considered in the past studies (only determining, in general, either the fatality rate is high or low but without any representation of uncertainty degree). Additionally, the effective safety management recommendations are hereby discussed to reduce the coal mine fatalities in the coal mines in Pakistan.

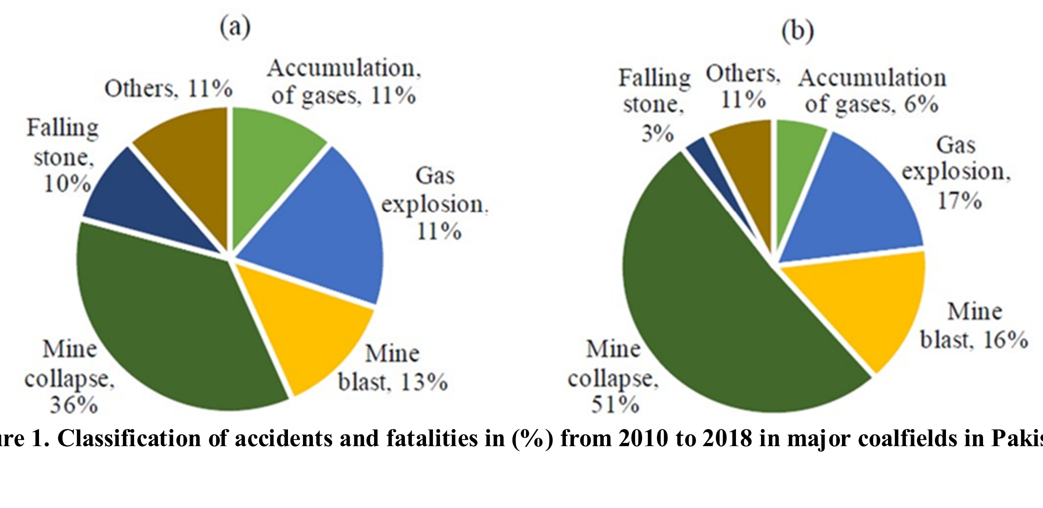

Figure 1. Classification of accidents and fatalities in (%) from 2010 to 2018 in major coalfields in Pakistan.

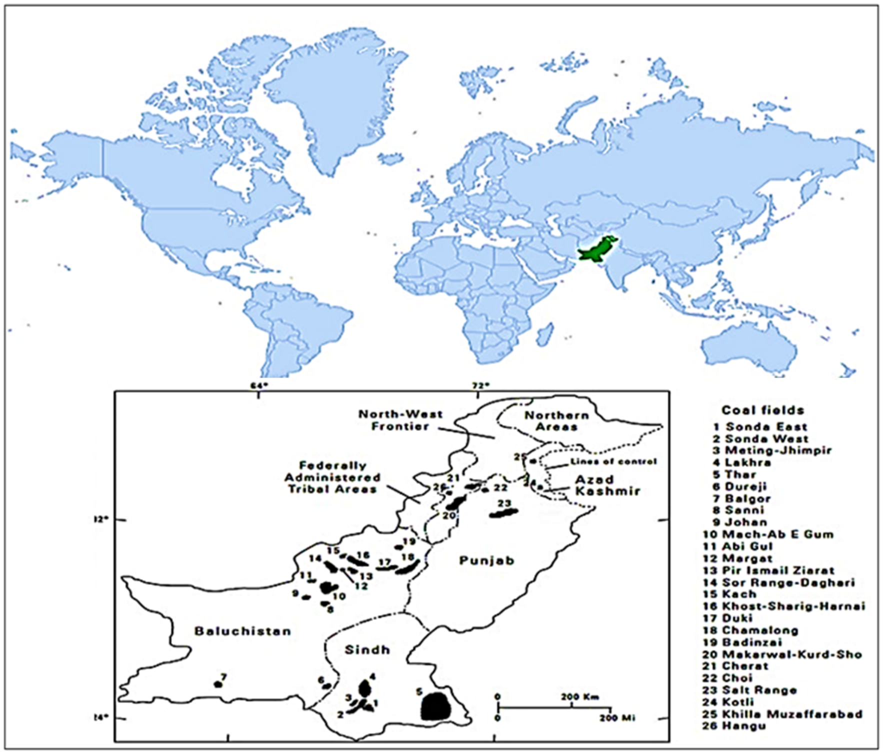

Figure 2. Spatial location of Pakistan and its major coal fields (a modified version of [28])

Figure 3. Coal mining practices in Pakistan. [29-30]

2. An Overview of Coal Mining Practices in Pakistan

Pakistan is a coal-rich country and is ranked 7th among the top-20 countries around the globe in terms of coal potential [6] with Thar Coalfield as the main coal reserve. The total coal reserves in this country are about 200 billion tons. However, due to the lack of financial resources and technical skills, this specific sector has not been adequately focused on in the past years. As compared with the other countries like China and India, the Pakistan's mine management system is failing to fulfill the international safety standards, and as a result, there are more and more fatal accidents.

The recent studies [31-32] have recommended more specific, economic, and safe coal production methods for the development of huge coal reserves at Thar Coalfield in Pakistan. The total annual coal production in Pakistan is approximately 4 million tons, and more than 4 million tons of coal are imported annually [33]. At the present time, coal is mostly produced by employing the traditional underground mining methods such as “longwall mining and room-and-pillar mining” [18]. The common accidents in the Pakistan underground coal mines are accumulation of gases, gas explosion, mine blast, mine collapse, and falling stones. Accordingly, the maximum number of fatal accidents is caused by mine collapse, gas explosion, and mine blast (clearly presented in Figure 1.

Due to the lack of technical skills and economic constraints, there is no effective mechanization system in the Pakistan coal mines; therefore, coal is extracted manually by applying human-work efforts with a traditional tool called pickaxe. Except for few mines, animals like donkeys and mules are used as a source of conveyance (haulage) of coal from the underground to the surface.

Thus the high rate of fatalities in Pakistan is accounted for through such types of accidents, which is a key objective of this work. Furthermore, the working conditions develop a terrifying situation for the life of the coal mine workers. Therefore, Pakistan has to take major structural and safety management developments such as "application of engineering design, adoption of effective technologies, administration of safety laws, and additional efforts for workforce education-related safety" [11]. Figure 2 shows the locations of the major coalfields in Pakistan. Figure 3 shows the coal mining practices in Pakistan.

3. Materials and Methods

3.1. Fuzzy Logic

Fuzzy logic is a super set of Boolean logic, which is now considered as a very potential topic in artificial intelligence. Boolean logic is actually a conventional method of representation in the form of 0 and 1 that represent the actions in a discrete way, i.e. either the answer is completely true or completely false [34-36]. However, when the action is going to be represented in a continuous way, where the Boolean logic fails, for example, today I have eaten a meal (meaning the action is completely true or 1) or I have not eaten a meal (meaning the action is completely false or 0), which can completely correspond to the Boolean logic either the value is 0 or 1 [37]. To the contrary, fuzzy is an advanced representation of logic through which we can discuss firstly to represent the uncertainty that results and the details in a totally unknown extent; for example, simply today, I ate too much meal or I ate too little meal. In the same manner, tonight, I slept a lot or vice versa, which we do not know the actual intensity or degree of such actions. Therefore, the fuzzy logic method is essential here to quantify or represent the actual intensity (continuous value) of such uncertainties. In parallel, "in fuzzy", the values are indicated by a number (called a truth value) in the range from 0 to 1, where 0 represents the absolute falseness and 1 represents the absolute truth. While this range evokes the idea of probability, fuzzy logic and fuzzy sets operate quite differently from probability" [37]. Secondly, representing the degree means, as mentioned in Boolean logic, I ate too much meal but we do not know the exact figure of meals like someone that can eat 1 meal, 2 meals or 3 meals are enough. Conversely, someone can eat 5 meals or more in a day, which may not be sufficient. Thus again, mentioning the fuzzy logic technique is important here, which gives us the actual uncertainty value of the overall situation.

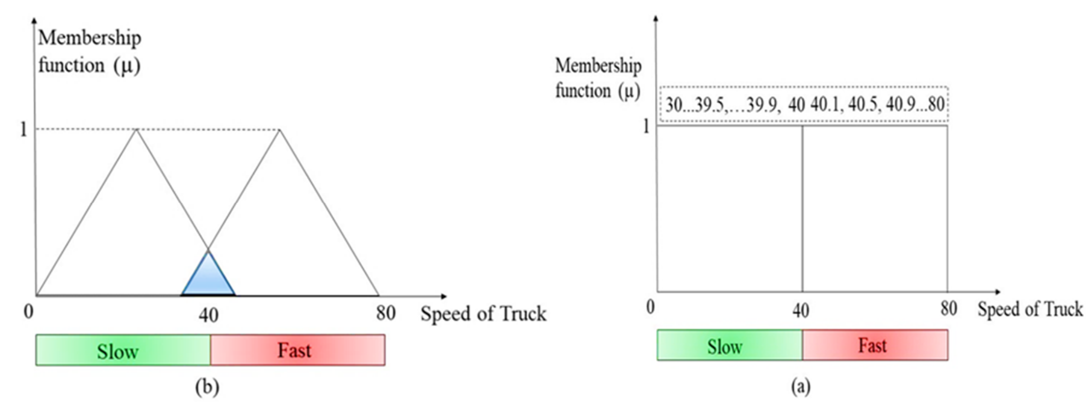

Figure 4. Differentiation between fuzzy logic and Boolean logic

Furthermore, for better differentiation between the fuzzy logic and Boolean logic, presented In Figures 4(a) and 4(b), the x-axis coordinate denotes the speed of a truck and the y-axis coordinate denotes the membership function (μ). For the membership function (μ), we are actually talking about the data whose membership (here, membership means the value that belongs to 0 and 1) belong to or not between; generally, we have values like 0 and 1; thus the membership value must fit in the range between 0 and 1 (such as 0.1, 0.2, 0.3 or 1.1, 1.2, 1.3). However, Boolean logic only shows the membership value of 0 (meaning false or 1 (meaning true), and there will be no uncertain value like in the fuzzy logic technique. In addition, to better understand the Boolean logic, let's take an example, in Figure 4 (a) when the speed of a truck is 30 means its membership value is 1. In the same manner, i.e. the speed of a car is 50 means its membership value is 1. However, if the speed of a truck is in the range of 40-50, like 39.1, 39.8 or 39.9 and 40.1, 40.5 or 40, the immediate transition of consequences causes a huge misunderstanding. According to the rule, when a driver is driving a truck, he is required to press the brake if the speed of the truck is higher than 40 (here, may be 40.1, 40.2). Contrariwise, the driver is required to accelerate the truck when the speed is less than 40 (here, may be 39.1, 39.8 or 39.9) and repetition of the same action can oscillate the speed value continuously. For a proper representation of the oscillated speed value, in other words, instead of immediate transition, there should be a little flexibility that is actually provided by the fuzzy logic [38]. In Figure 4(b), where the speed value is not going to immediately transit when about 40 as represented in the shaded small triangle zone means the speed of the truck is in the range between slow and fast, which is signified through a small extent of flexibility. Therefore, in Figure 4(b), the fuzzy logic technique is an accurate way to represent the data rather than in Figure 4(a) that shows problematic results.

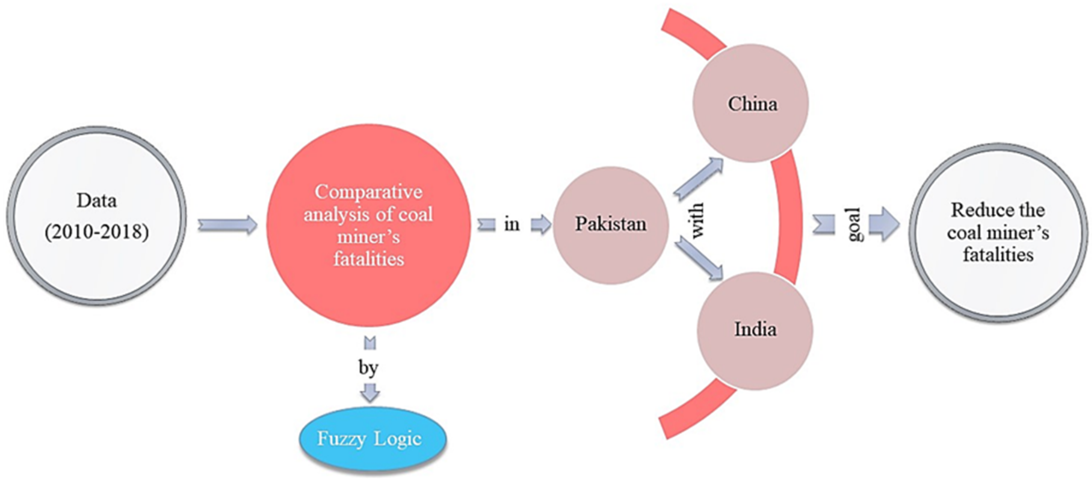

Figure 5. Flow chart

3.2. Methodology

Looking at Figure 5, the methodological approach used to accomplish the objective of this work is to reduce the coal miner's fatalities by the fuzzy logic analysis of the data from 2010 to 2018 for the fatality rate in the coal mines in Pakistan compared with China and India. Several data sources [12, 39-57] were used to collect the data on the fatality rates. There are many other approaches for such an analysis but in this work, we only used the fuzzy logic technique to achieve a proper representation and to calculate the membership function (μ) value for the fatality rate using Eqs. 1 and 2 [31] for China and India, respectively, in order to clearly understand its effect on the fatality rate in Pakistan.

The degree of low or high fatalities or the membership function (μ) value of the fatality rate can be determined as follows:

$$\left\{\begin{array}{ll} 0, \text{ if the fatality rate (FR) per million tons (x)} \leq 0.31 & \\ \dfrac{\boldsymbol{FR\ per\ million\ tons\ (x) - 0.31}}{\boldsymbol{0.69}}, & \boldsymbol{if\ 0.31\ Avg.FR\ per\ millions\ tons\ (x) < 1} \\ 1, \text{ if FR per million tons (x)} \geq 1 & \end{array}\right\} \quad \textbf{Eq. (1)}$$

$$\left\{\begin{array}{ll} 0, \text{ if the FR per million tons (x)} \leq 0.12 & \\ \dfrac{\boldsymbol{FR\ per\ million\ tons\ (x) - 0.12}}{\boldsymbol{0.88}}, & \boldsymbol{if\ 0.12\ Avg.FR\ per\ millions\ tons\ (x) < 1} \\ 1, \text{ if FR per million tons (x)} \geq 1 & \end{array}\right\} \quad \textbf{Eq. (2)}$$

where:

FR per million tons (x) is the fatality rate in Pakistan from 2010-2018,

0.31 is the Avg. FR per million tons in China,

0.12 is the Avg. FR per million tons in India,

0.69 is the gap between 0.31 and 1,

0.88 is the gap between 0.12 and 1.

Finally, let μ be a mapping of a reference set U, μ:U→ [0, 1]. Then μ determines a fuzzy sub-set, denoted by A, in U; μ is sometimes indicated by μA; μA(u) is called the grade of membership of μ in A. If μA(u) is either 0 or 1, the fuzzy set A will be understood as an 'ordinary sub-set'.

4. Analysis of Results and Discussion

Based on the data from 2010 to 2018, the coal mine fatality rates in Pakistan, China, and India were statistically studied. As shown in Table 1, the results of this work reveal different values of fatality rate in each year. Based on Table 2, the average fatality rates in Pakistan, China, and India are 0.99 (~1), 0.31, and 0.12, respectively. Employing the fatality rates per 1000 persons, it was found that the accident rate in the Pakistan coal mines is high, as compared with China and India, which is very high and not acceptable for the safety of the coal miners in Pakistan.

Table 1. Fatality rates per million tons in Pakistan, China, and India from 2010 to 2018.

Year	Pakistan	China	India
2010	0.74	0.803	0.2
2011	2.44	0.564	0.11
2012	0.82	0.374	0.12
2013	0.46	0.293	0.13
2014	0.26	0.257	0.09
2015	1.74	0.203	0.08
2016	0.43	0.156	0.16
2017	0.39	0.106	0.1
2018	1.6	0.093	0.089

Table 2. Average fatality rates per million tons in Pakistan, China, and India from 2010 to 2018.

Year	Pakistan	China	India
2010-2018	0.99 (~1)	0.31	0.12

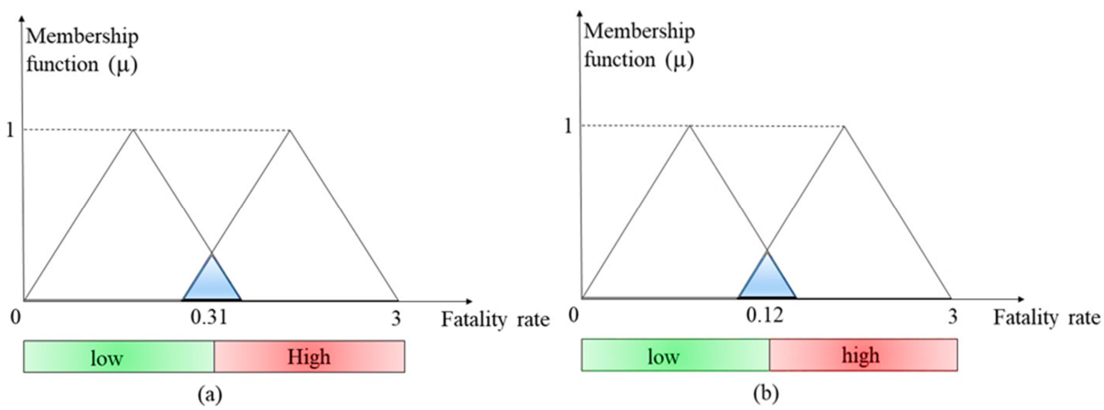

Figure 6. (a). Flexibility value of fatality rate w.r.t China, (b). Flexibility value of fatality rate w.r.t India.

The average fatality rates per million tons in Pakistan, China, and India were 0.99 (~1), 0.31, and 0.12, respectively, which were used for the fuzzy logic analysis in this work. Figure 7 and Table 3 refer to Figure 6 that represent the membership function (μ) values (flexibility value or degree of low or high fatality rate per million tons) in Pakistan with respect to China and India from 2010 to 2018. The findings show that the fatality rates in 2011, 2015, and 2018 are 2.44, 1.74, and 1.6, respectively, whose membership function (μ) values represent the absolute truth and denote that these values are alarming for the high fatalities of the coal miners. In the same manner, except for 2014, where 0 represents an absolute falseness, the results for the remaining years indicate high fatality rates with a small extent of their corresponding membership function (μ) values with 0.623, 0.739, 0.219, 0.173, and 0.115, respectively, compared with China. Likewise, the membership function (μ) values compared with India for the remaining years are 0.704, 0.795, 0.379, 0.159, 0.352, and 0.306, respectively.

Furthermore, as shown in Table 1, the yearly fatality rate per million tons in Pakistan compared with China and India were also used for the fuzzy logic analysis. Similarly, Figure 8 and Table 4 refer to Figure 6 that represent the membership function (μ) values (flexibility value of fatality rate per million tons) in Pakistan with respect to China and

India from 2010 to 2018. Consequently, the fatality rates in 2011, 2015, and 2018 are 2.44, 1.74, and 1.6, respectively, whose membership (μ) values ≥ 1 represent the absolute truth and represent that these values are distressing for the growth rate of the fatalities of the coal miners. In addition, except for 2010, where 0 represents the absolute falseness, the results for the remaining years show rising fatality rates corresponding to the membership (μ) values with 0.714, 0.24, 0.01, 0.324, and 0.317, respectively, compared with China. Likewise, the membership (μ) values, compared with India, in the remaining years are 0.675, 0.795, 0.386, 0.186, 0.321, and 0.322, respectively.

Hence, comparing the fuzzy logic technique with the other relevant methods like Boolean or classical set theory, it is more advantageous for an accurate representation of the relevant results. Moreover, the results of this work guide us to pay more attention to the safety of coal mine workers in terms of strengthening the safety supervision, provision of personal protective equipment, and upgrading the latest mining methods, especially for the underground coal mines in Pakistan, to overcome such a mine safety crisis.

Table 3. Membership function (μ) values for Pakistan with respect to China and India from 2010 to 2018 by the fuzzy logic analysis using the average fatality rates.

Year	China (μ)	India (μ)
2010	(0.74, 0.623)	(0.74, 0.704)
2011	(2.44, 1)	(2.44, 1)
2012	(0.82, 0.739)	(0.82, 0.795)
2013	(0.46, 0.217)	0.386
2014	(0.26, 0)	(0.26, 0.159)
2015	(1.74, 1)	(1.74, 1)
2016	(0.43, 0.173)	(0.43, 0.352)
2017	(0.39, 0.115)	(0.39, 0.306)
2018	(1.6, 1)	(1.6, 1)

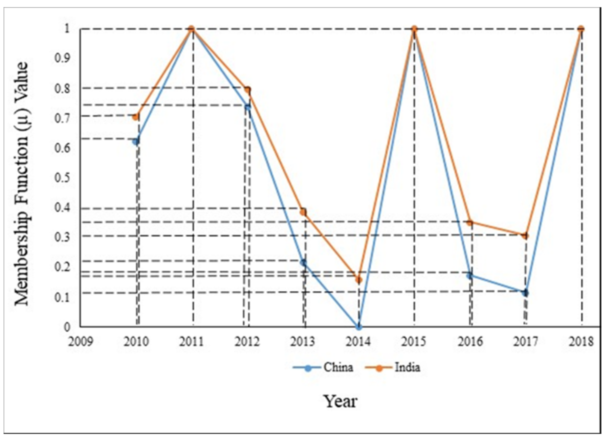

Figure 7. Representation of the membership function (μ) values for Pakistan with respect to China and India from 2010 to 2018 using the average fatality rates.

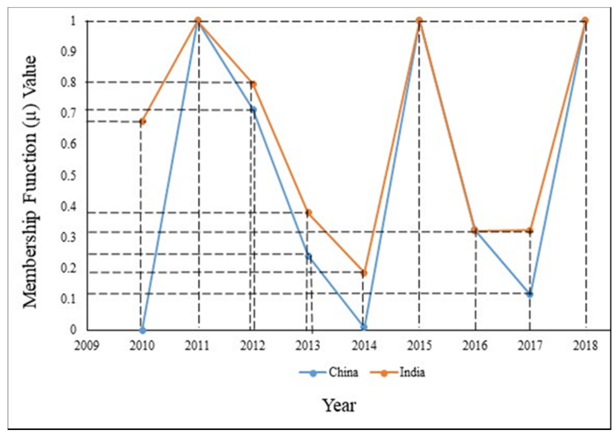

Figure 8. Representation of the membership function (μ) values for Pakistan with respect to China and India from 2010 to 2018 using yearwise fatality rates.

Table 4. Membership function (μ) values for Pakistan with respect to China and India from 2010 to 2018 by the fuzzy logic analysis using yearwise fatality rates.

Year	China (μ)	India (μ)
2010	(0.74, 0)	(0.74, 0.675)
2011	(2.44, 1)	(2.44, 1)
2012	(0.82, 0.714)	(0.82, 0.795)
2013	(0.46, 0.24)	(0.46, 0.379)
2014	(0.26, 0.01)	(0.26, 0.186)
2015	(1.74, 1)	(1.74, 1)
2016	(0.43, 0.324)	(0.43, 0.321)
2017	(0.39, 0.317)	(0.39, 0.322)
2018	(1.6, 1)	(1.6, 1)

5. Conclusions

Coal mining is considered as a very hazardous job because of its inherent hazardous working conditions that often result in fatalities or fatal accidents. Thus the fatality rate per million ton of coal is increasing, which is not acceptable for the safety of the mining workforces in Pakistan compared with its neighbouring countries like China and India. Based on the fuzzy logic analysis, it was concluded that both the average and yearwise fatality rates in 2011, 2015, and 2018 were 2.44, 1.74, and 1.6 respectively, in fuzzy logic whose membership function (μ) value is ≥ 1, which means that the situation is very alarming for the high fatalities of coal miners, especially in Pakistan. In addition, the fuzzy logic membership function (μ) values compared with India and China in the remaining years were also measured. Moreover, in this work, we considered the past research works that had not been properly focused on in depth. The key factors for the growing rate of fatalties in Pakistan are as follows: mine collapse and blast, accumulation of gas, gas explosion, and falling stones. Therefore, the effects of these distressing factors, which are the major causes of the miner fatalities must be reduced by effective safety measures.

6. Recommendations

As a result of the laxity of safety supervision and practical actions, the safe coal production level in Pakistan has decreased continuously. In this work, we suggested the following effective safety recommendations to control the increased rate of fatalities in the coal mines in Pakistan.

i. **Safety Education and Training:** Lack of mine safety education at the managerial and worker levels is multiplying the dangers of coal mining in Pakistan. Special educational and training centers should be established. Additionally, more seminars and conferences should be held in Pakistan to raise the awareness about the international mining safety practices.

ii. **Child Labor and Illegal Mining:** Child labor and illegal mining is another major problem related to mine safety and fatal accidents in Pakistan. The authorities are required to be much more vigilant at stopping these dangerous illegal practices to the best of their ability.

iii. **Lack of Technology:** Deficiency of an advanced technology is another hurdle faced by the coal mining industry in Pakistan. The government should make all the necessary efforts to import the latest safety equipment to safeguard the life of the poor coal mining working class.

Also this work recommends the following essential points to reduce the fatalities caused by different types of fatal accidents:

i. **Mine Collapse and Blast:** Mine collapse and blast are the major sources of life loss in the Pakistani coal mines. This implies that the structural integrity of the Pakistan coal mines is questionable. Major mine structures should be examined by the government, and the necessary maintenance and repairs should be carried out on an emergency basis.

ii. **Accumulation of Gas:** Prevention of the accumulation of toxic gases in the coal mines can only be attained by employing a proper ventilation system to drain out the unwanted gases prior to or during the mining operations. Additionally, the mine inspectors are required to inspect the mine on a daily basis to ensure the safety of the mine workers from the higher quantities of harmful gases.

iii. **Gas Explosion:** Gas explosion occurs due to the presence of the methane gas associated with a heat source and an inadequate ventilation to dilute the gas level to below the explosion point. Therefore, the basic helpful approaches are to inhibit the presence and build-up of ignitable bodies of methane and to eliminate the sources of ignition such as open fires, frictional and electrical flashes, heat from spontaneously combusting coal, and heat from the mining equipment; however, this is not restricted to the hot exhaust manifolds and frictional heat (belts, brakes [17-18]. Additionally, a sufficient supply of ventilation is suggested to reduce the gas explosions in the coal mines.

iv. **Falling Stones:** Falling stones is one of the significant sources of underground mining fatalities. The key preventative procedures to avoid such accidents by regular checking of rock faces and inspection of loose rocks and tension cracks to avoid stones falling from high walls are essential.

Finally, more resources and budget should be allocated to mine inspection and relevant law and enforcement agencies so that they could perform their duties in ensuring abiding the mining safety laws and policies in Pakistan.

7. Future work

In the current work, we only used the fuzzy logic technique for a comparative analysis of the coal miner's fatalities in Pakistan. However, this work can be expanded to collect more data and use the fuzzy fault tree analysis and fuzzy analytic hierarchy process (FAHP) to better understand the subject matter.

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Conflict of Interest

The authors declare no potential conflict of interest.

References

[1]. Directorate General of Mines Safety Annual Report. Ministry of Labour and Employment, Government of India 2014.

[2]. Directorate General of Mines Safety Annual Report. Ministry of Labour and Employment, Government of India 2015.

[3]. Sajid, M. J., Shahani, N. and Ali, M. (2019). Calculating inter-sectoral carbon flows of a mining sector via hypothetical extraction method. Journal of Mining and Environment. 10 (4): 853-867.

[4]. Donoghue AM. Occupational health hazards in mining: an overview. Occupational Medicine (London) 2004; 54: 283–289. DOI: 10.1093/occmed/kqh072.

[5]. Sari, M., Selcuk, A.S., Karpuz, C. and Duzgun, H.S.B. (2009). Stochastic modeling of accident risks associated with an underground coal mine in Turkey. Safety science. 47 (1): 78-87.

[6]. Shahani, N.M., Sajid, M.J., Zheng, X., Jiskani, I.M., Brohi, M.A., Ali, M. and Qureshi, A.R. (2019). Fault tree analysis and prevention strategies for gas explosion in underground coal mines of Pakistan. Mining of Mineral Deposits.

[7]. Liu, Q., Meng, X., Hassall, M. and Li, X. (2016). Accident-causing mechanism in coal mines based on hazards and polarized management. Safety science. 85: 276-281.

[8]. Liu, Q., Li, X. and Meng, X. (2019). Effectiveness research on the multi-player evolutionary game of coal-mine safety regulation in China based on system dynamics. Safety science, 111, 224-233.

[9]. Lin, B.Q., Chang, J.H. and Zhai, C. (2006). Analysis on coal mine safety situation in China and its countermeasures. China Safety Science Journal. 16 (5): 42-46.

[10]. Hai-bin, L.I.U. and Hui, L.G.R.H. (2007). Study on characteristics of coal mine intrinsic safety and strategies of management. China Safety Science Journal (CSSJ). (4): 12.

[11]. Jiskani, I.M., Ullah, B., Shah, K.S., Bacha, S., Shahani, N.M., Ali, M. and Qureshi, A.R. (2019). Overcoming mine safety crisis in Pakistan: An appraisal. Process Safety Progress. 38 (4): e12041.

[12]. Tripathy, D.P. and Ala, C.K. (2018). Identification of safety hazards in Indian underground coal mines. Journal of Sustainable Mining. 17 (4): 175-183.

[13]. Wu, Z. (2007). Study on some strategy problems of China's work safety by 2020. Journal of Safety Science and Technology. 3 (1): 3-7.

[14]. Wang, K. (2008). Chemical production accident analysis and prevention.

[15]. Boal, W.M. (2018). Work intensity and worker safety in early twentieth-century coal mining. Explorations in Economic History, 70, 132-149.

[16]. WANG, C., ZHANG, W.M., WANG, P.F., Lei, Y. and Zhang, S.S. (2014). Effect of submerged vegetation on the flowing structure and the sediment resuspension under different wind-wave movement conditions [J]. Journal of Safety and Environment. 14 (2): 107-111.

[17]. Shahani, N.M., Sajid, M.J., Brohi, M.A., Qureshi, A.R., Shahani, L.B., Bacha, S. and Ullah, B. (2019). An empirical analysis of fatal accidents in the coal mines of Pakistan. In Proceedings of the International Conference on Energy, Resources, Environment and Sustainable Development, Xuzhou, Jiangsu Province, China (pp. 726-733).

[18]. Shahani, N.M., Sajid, M.J., Zheng, X., Jiskani, I.M., Brohi, M.A., Ali, M. and Qureshi, A.R. (2019). Fault tree analysis and prevention strategies for gas explosion in underground coal mines of Pakistan. Mining of Mineral Deposits.

[19]. Xie, X., Fu, G., Xue, Y., Zhao, Z., Chen, P., Lu, B. and Jiang, S. (2019). Risk prediction and factors risk analysis based on IFOA-GRNN and apriori algorithms: Application of artificial intelligence in accident prevention. Process Safety and Environmental Protection, 122, 169-184.

[20]. Ghasemi, E. and Ataei, M. (2013). Application of fuzzy logic for predicting roof fall rate in coal mines. Neural computing and applications. 22 (1): 311-321.

[21]. Mohseni, M. and Ataei, M. (2016). Risk prediction based on a time series case study: Tazareh coal mine.

[22]. Ghasemi, E., Ataei, M. and Shahriar, K. (2017). Improving the method of roof fall susceptibility assessment based on fuzzy approach. Archives of Mining Sciences. 62 (1): 13-32.

[23]. Ataei, M., Khalokakaei, R. and Hossieni, M. (2009). Determination of coal mine mechanization using fuzzy logic. Mining Science and Technology (China). 19 (2): 149-154.

[24]. Sereshki, F., Daftaribeshli, A. and Ataei, M. (2010). A Mamdani fuzzy inference system for rock mass rating (RMR) and its use in rock mass parameters estimation. Archives of Mining Sciences, 55(4), 947-960.

[25]. Daftaribesheli, A., Ataei, M. and Sereshki, F. (2011). Assessment of rock slope stability using the Fuzzy Slope Mass Rating (FSMR) system. Applied Soft Computing. 11 (8): 4465-4473.

[26]. Khalokakaie, R., Ataei, M., Mikaiel, R. and Hoseinie, S.H. (2011). A fuzzy logic based classification for assessing of rock mass drillability. International Journal of Mining and Mineral Engineering. 3 (4): 278-289.

[27]. Hosseini, S.A.A., Ataei, M., Hosseini, S.M. and Akhyani, M. (2012). Application of fuzzy logic for determining of coal mine mechanization. Journal of Coal Science and Engineering (China). 18 (3): 225-231.

[28]. Sohail, M.T., Huang, D., Bailey, E., Akhtar, M.M. and Talib, M.A. (2013). Regulatory framework of mineral resources sector in Pakistan and investment proposal to Chinese companies in Pakistan. American Journal of Industrial and Business Management. 3 (05): 514.

[29]. http://www.industriall-union.org/another-coal-mine-explosion-in-pakistan-five-killed-and-eight-injured/ [5 April 2016].

[30]. https://www.ibtimes.co.uk/children-donkeys-labouring-underground-coal-mine-punjab-province-pakistan-145903 7/ [30 July 2014].

[31]. Shahani, N.M., Wan, Z., Guichen, L., Siddiqui, F.I., Pathan, A.G., Yang, P. and Liu, S. (2019). Numerical analysis of top coal recovery ratio by using discrete element method. Pakistan Journal of Engineering and Applied Sciences, 24(1).

[32]. Shahani, N.M., Wan, Z., Zheng, X., Guichen, L., Liu, C., Siddiqui, F.I. and Bin, G. (2020). Numerical modeling of longwall top coal caving method at thar coalfield. Journal of Metals, Materials and Minerals. 30 (1).

[33]. http://www.finance.gov.pk/survey/chapters_13/14-Energy.pdf/ [2012-13].

[34]. Zadeh, L.A. (1965). Fuzzy collection. Inf. Control, 8, 338-356.

[35]. Bonham-Carter, G.F. (1994). Geographic information systems for geoscientists-modeling with GIS. Computer methods in the geoscientists. 13: 398.

[36]. Zafar MA. Artificial Intelligence (CS607). Virtual University of Pakistan https://vulms.vu.edu.pk/ Courses/CS607/ Downloads/ AI_Complete_ hand outs_for_Printing.pdf.

[37]. Muthumaniraja, CK, Anbazhagan S, Jothibasu A, Chinnamuthu M. Remote Sensing and Fuzzy Logic Approach for Artificial Recharge Studies in Hard Rock Terrain of South India. GIS and Geostatistical Techniques for Groundwater Science 2019; 91-112. DOI: 10.1016/B978-0-12-815413-7.00008-0.

[38]. Ertuğrul, İ. and Tuş, A. (2007). Interactive fuzzy linear programming and an application sample at a textile firm. Fuzzy Optimization and Decision Making. 6 (1): 29-49.

[39]. Chu, C., Jain, R., Muradian, N. and Zhang, G. (2016). Statistical analysis of coal mining safety in China with reference to the impact of technology. Journal of the Southern African Institute of Mining and Metallurgy, 116(1), 73-78.

[40]. https://menafn.com/1097893225/3-laborers-killed-as-coal-mine-collapses-in-SW-Pakistan/ [17 December 2018].

[41]. https://telanganatoday.com/23-coal-miners-killed-due-to-gas-explosion-in-pakistan/ [6 May 2018].

[42]. https://www.bexpress.com.pk/2017/09/httpwp-mep5f0gk-92d/ [12 September 2017].

[43]. https://menafn.com/1097893225/3-laborers-killed-as-coal-mine-collapses-in-SW-Pakistan/ [27 December 2018].

[44]. https://www.dawn.com/news/1411903/ [3 June 2018].

[45]. https://news.mb.com.ph/2018/09/12/nine-killed-in-pakistan-coal-mine-collapse/ [12 September 2018].

[46]. http://www.coalresource.com/news/4585979/info/ [21 January 2019].

[47]. http://www.chinacaj.net/i,16,7559,0.html/ [5 February 2018].

[48]. http://www.industriall-union.org/sites/default/files/ uploads/documents/2016/Pakistan/mining_accidents_in_pakistan_2010-2016.pdf/[2010-2016].

[49]. http://www.industriall-union.org/pakistan-two-coal-miners-killed-and-one-seriously-injured/ [13 February 2017].

[50]. http://www.industriall-union.org/pakistan-fatal-mine-accidents-kill-seven-coal-miners/ [29 May 2017].

[51]. http://www.industriall-union.org/four-coal-miners-die-in-pakistan/[12 September 2019].

[52]. http://www.industriall-union.org/pakistan-anger-soars-over-frequent-fatalities-;/ [2018].

[53]. http://www.industriall-union.org/pakistan-11-workers-killed-in-series-of-mine-accidents/ [5 April 2018].

[54]. http://www.industriall-union.org/pakistans-deadly-mines-23-workers-killed-in-one-day/ [7 May 2018].

[55]. http://www.industriall-union.org/pakistan-19-miners-including-rescue-workers-die-in-coal-mine-accident/ [16 August 2018].

[56]. https://ycharts.com/indicators/pakistan_coal_production/ [1981-2017].

[57]. Ministry of Coal, Safety in Coal Mines. National Informatics Centre (NIC), Govt. of India 2018.

آنالیز مقایسه‌ای تلفات معدنکاران زغال‌سنگ توسط منطق فازی

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چکیده:

در این مقاله برای اولین بار یک تحلیل مناسب از شدت و میزان نرخ رشد تلافات و مرگ و میر کارگران در معادن زغال سنگ پاکستان بین سال‌های ۲۰۱۰ تا ۲۰۱۸ با استفاده از منطق فازی صورت گرفته است. نتایج بدست آمده با شرایط معادن هند و چین به منظور کاهش تلفات کارگران مقایسه شد. میانگین و میزان مرگ و میر سالانه در معادن پاکستان با داده‌های معادن چین و هند مقایسه شد، و از نتایج در تکنیک منطق فازی به منظور محاسبه درجه واقعی انعطاف پذیری در مورد تلفات فزاینده استفاده شد. یافته‌ها نشان داد که میزان نرخ میانگین تلفات میان سال‌های ۲۰۱۰ تا ۲۰۱۸ و نرخ تلفات سالیانه در سال‌های ۲۰۱۱، ۲۰۱۵ و ۲۰۱۸ به ترتیب برابر ۲/۴۴، ۱/۷۴ و ۱/۶ است. در تکنیک منطق فازی، متغیرهایی که مقادیر عضویت (μ) آنها ≥ ۱ هستند حقیقت مطلق را نشان می‌دهند. مقدار تابع عضویت برای سال‌های ۲۰۱۱، ۲۰۱۵ و ۲۰۱۸ از نظر تلفات کارگران معادن زغال سنگ بسیار هشدار دهنده است. بطور مشابه به جز سال‌های ۲۰۱۰ و ۲۰۱۴ که مقدار نشان داده شده برابر ۱۰ است که مطلقاً اشتباه است، نتایج بدست آمده برای باقی سال‌ها میزان مرگ و میر بالایی را نشان می‌دهد که انعطاف پذیری (یا میزان کمی) از ارزش عضویت مربوطه (μ) با استفاده از تجزیه و تحلیل و میانگین سالیانه در مقایسه با چین به ترتیب عبارت است از ۰,۶۲۳، ۰,۷۳۹، ۰,۲۱۹، ۰,۱۷۳، ۰/۱۱۵ و ۰,۷۱۴، ۰,۲۴، ۰,۰۱، ۰,۳۲۴ و ۰,۳۱۷. به همین ترتیب مقادیر تابع عضویت منطق فازی (μ) در مقایسه با هند در سالهای باقیمانده نیز به ترتیب ۰/۷۰۴، ۰/۷۹۵، ۰/۳۸۶، ۰/۱۵۹، ۰/۳۵۲ و ۰/۳۰۶ و ۰/۶۷۵، ۰/۷۹۵، ۰/۳۸۶، ۰/۱۸۶، ۰/۳۲۱ و ۰/۳۲۲ است. تجزیه و تحلیل منطق فازی پیشنهادی بر اساس تئوری مجموعه های فازی برای شناسایی صحیح تلفات معدنچیان و همچنین پیشنهاد اجرای برنامه‌های مناسب برای کاهش تلفات در معادن زغال‌سنگ در پاکستان پایه گذاری شده است.

کلمات کلیدی: ایمنی معدن ذغال‌سنگ، تجزیه و تحلیل مقایسه‌ای ، میزان تلفات، منطق فازی، مدیریت ایمنی.