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ОЦЕНКА СОВОКУПНОГО ВЛИЯНИЯ ПРОИЗВОДСТВЕННОГО ТРАВМАТИЗМА И ПРОФЕССИОНАЛЬНЫХ ЗАБОЛЕВАНИЙ НА СОСТОЯНИЕ ОХРАНЫ ТРУДА В УГОЛЬНОЙ ПРОМЫШЛЕННОСТИ

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Аннотация: угледобывающая промышленность характеризуется высокой тяжестью труда и воздействием большого количества вредных и опасных производственных факторов на рабочих в процессе трудовой деятельности. В связи с чем, уровень производственного травматизма и профессиональных заболеваний остается на высоком уровне, несмотря на совершенствование охраны труда и модернизацию рабочего процесса. Цель данного исследования — оценить состояние охраны труда в угольной промышленности на основе сопоставления рисков травматизма и профзаболеваний. В работе выполнен анализ рисков травматизма и профзаболеваний для различных угледобывающих регионов России, в результате чего особое внимание было уделено Кемеровской области (Кузбасс), поскольку в данном регионе рассматриваемые риски остаются на недопустимо высоком уровне. Новизна результатов проведенных исследований заключается в оценке совокупного влияния травматизма и профзаболеваний на угледобывающих предприятиях. Полученные зависимости показали, что с течением времени, влияние профзаболеваний рабочих приводит к повышению риска травматизма.

Ключевые слова: угольная промышленность, производственный травматизм, профессиональные заболевания, риск-ориентированный подход, охрана труда, регрессионная статистика, дисперсионный анализ.

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Assessment of the cumulative impact of occupational injuries and diseases on the state of labor protection in the coal industry

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Abstract: The coal mining industry is characterised by heavy workloads and exposure of workers to a large number of harmful and hazardous production factors in the course of their work activities. In this connection, the level of occupational injuries and occupational diseases remains at a high level, despite the improvement of labour protection and modernization of the working process. The purpose of this study is to assess the state of occupational safety in the coal industry by comparing the risks of injuries and occupational diseases. The paper analyzes the risks of injuries and occupational diseases for different coal mining regions of Russia, with special attention to the Kemerovo region (Kuzbass), as in this region the considered risks remain at an unacceptably high level. The novelty of the research findings lies in assessing the cumulative impact of injuries and occupational diseases in coal mining enterprises. The dependencies obtained showed that over time, the impact of occupational diseases of workers leads to an increase in the risk of injury.

Key words: coal industry, occupational injuries, occupational diseases, risk-based approach, occupational health and safety, regression statistics, analysis of variance.

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1. Introduction

The promotion of occupational safety in the workplace is a priority for many countries. The result of successfully tackling occupational safety issues to reduce occupational injuries and diseases is increased operational efficiency and improved economic performance of enterprises. Neglect or insufficient attention to occupational health and safety, in addition to technical and economic damage, can lead to serious social consequences [1,2].

Safety issues are most relevant for the mining industry, as most of the enterprises are classified as hazardous production facilities. In this regard, there are many studies of mining and processing methods, global trends and the experience of foreign companies are investigated [3–8]. If we use the risk of occupational injuries and occupational diseases, calculated as the ratio of the number of accidents or diagnosed occupational diseases per year to the total number of workers, as an indicator of occupational safety, the risk of injuries and occupational diseases for the mining industry exceeds the average risk value for other industries in Russia by 4—5 times [9–11].

One of the important problems for the effective implementation of mining projects is taking into account the human factor [12, 13]. In the Russian Federation, this problem is exacerbated by the fact that more than 2 million people live on a vast territory with vast reserves of mineral resources, which requires the attraction of workers from other regions on a 'rotational' basis.

The highest risks of occupational injuries and occupational diseases are characteristic of coal mining enterprises, because coal mining is characterized by high intensity of workers' work, as well as working personnel are negatively affected by adverse environmental conditions of areas where people live, usually located in the vicinity of mining sites [14,15]. These causes result in a relatively high degree of air and water pollution, excessive noise and vibration levels. The importance of understanding these characteristics accompanying surface and underground coal mining is determined by the large number of coal-producing regions in the Russian Federation (Fig. 1).

Adverse climatic and environmental conditions of the regions where mining is carried out, in particular coal, along with the difficult working conditions of miners, determine a higher risk of occupational injuries and occupational diseases [17–19]. In order to reduce the risk it is necessary to continuously improve the system of occupational safety

Fig. 1. Distribution of coal production among constituent entities of the Russian Federation, million tonnes [16]

at coal mining enterprises, the first stage of which should be an assessment of the current state of occupational safety.

2. Materials and methods

The study of occupational injuries and occupational diseases in mining enterprises, as well as risk reduction of these indicators are devoted to the research of many domestic and foreign scientists: G. Z. Fineburg, I. L. Kravchuk, M. L. Rudakov, O. V. Vorobyeva, A. I. Fomin, V. A. Galkin, V. N. Kosterenko, E. M. Nevolina, A. V. Smolin, Y. V. Shuvalova, V. V. Smirnyakova and other authors [20–23]. But the assessment of the state of labour protection in the coal industry based on the comparison of risks of injuries and occupational diseases has not been carried out so far, which determines the relevance of this study.

There are many methods for analysing occupational injuries and illnesses, divided into three main groups: technical, statistical and probabilistic. Technical analysis examines accidents in order to identify the technical factors that have caused the injury and then to determine recommendations for the prevention of occupational injuries and diseases. Probabilistic methods of analysis use the apparatus of probability theory to assess occupational safety. Statistical methods of analysis are based on statistical data on accidents that have occurred and occupational diseases that have been detected. The aim of these methods is to assess the safety level of workers' working conditions. The following types of statistical methods of analysis can be distinguished: correlation (regression), topographical, tabular and the method based on the calculation of injury rates.

The correlation (regression) statistical method of analysis was chosen to assess the state of occupational safety in the coal industry based on the comparison of risks of injuries and occupational diseases. Correlation analysis is used to establish quantitative relationships between injury and occupational diseases indicators. The risk of occupational injuries and occupational diseases are stochastic variables, so the dependence between these indicators is not deterministic, but averaged. Statistical data from Rostrud and

Rostekhnadzor of the Russian Federation were used to determine the risks of occupational injuries and occupational diseases [24]. To calculate and analyse the risks in the coal mines of SUEK-Kuzbass JSC, the data presented in the company's statistical reports for the period from 2011 to 2021 was used.

The risks of occupational injuries and diseases were calculated for each year of the company's operation by dividing the number of accidents or diagnosed occupational diseases by the average number of workers. The 10-year average risk, standard deviation and standard error were then calculated. The statistical data were processed using the correlation and regression method, which made it possible to establish the dynamics of occupational injury and occupational diseases risk during the period in question.

3. Results and discussion

3.1. Risk of occupational injury

To calculate the risk of occupational injuries in the regions where coal mining takes place in Russia, statistical reporting data were used. The results are shown in Fig. 2. The risks of occupational injuries are presented as a linear correlation. The standard deviation (M) and standard error (SEM) are calculated for each relationship.

Fig. 2 shows that the highest risk of occupational injuries is in the Kemerovo region, where the Kuznetsk coal basin, one of the world's largest coal deposits, is located. There are 54.5 billion tonnes of coal reserves and 34 billion tonnes of lignite reserves. The occupational injury risks for other coal-mining regions are about the same. In general, coal-mining regions in Russia tend to reduce the level of injury risk over a 10-year period. The Republic of Sakha (Yakutia) contributes a certain dissonance to this trend, with an 11% increase in occupational injuries.

The linear correlations of injury risks over time shown in Fig. 2 have a correlation coefficient greater than 0.75 and have individual regression coefficients that define the dynamics of injury risks over a 10-year period.

Due to the highest risk of occupational injuries in the Kemerovo Region (Kuzbass), SUEK-Kuzbass Joint Stock Company, where open pit and underground

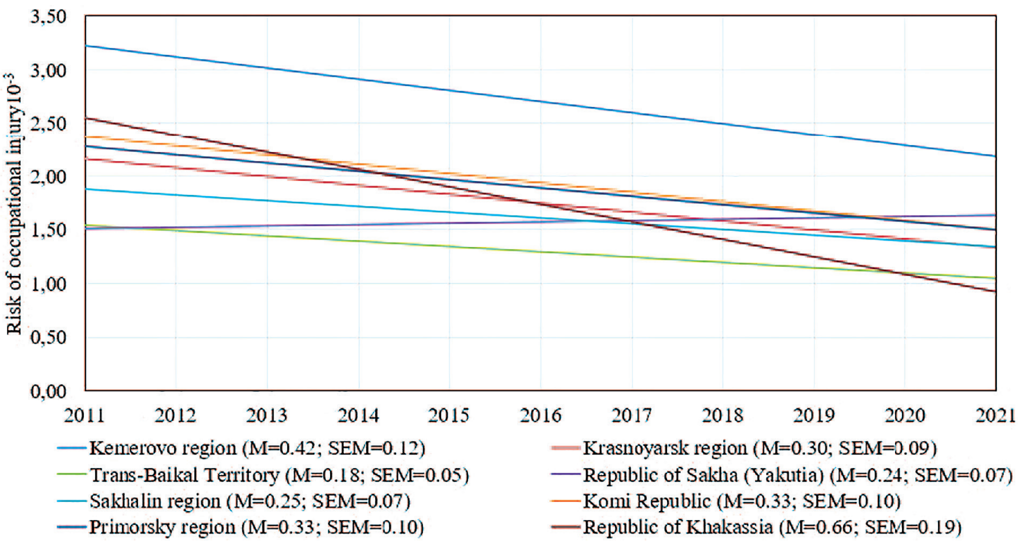

Fig. 2. Occupational injury risk in coal mining regions of Russia

coal mining are carried out, was chosen as an example of calculating occupational injury risks [25, 26]. The company includes: 8 mines and 2 open-pit mines. Special attention was paid to mines, as the risk of occupational injuries remains the highest in underground coal mining. The calculated risk values at the mines of SUEK-Kuzbass JSC are presented in the form of correlated linear relationships (Fig. 3).

Fig. 3 shows that for all mines of SUEK-Kuzbass JSC the risk of occupational injuries decreases over a 10-year period. The risk dynamics is described by linear correlation with a correlation coefficient exceeding 0.7, with a reliability of 0.95. The highest risk of injury is characteristic of the Yalevsky mine. V. D. Yalevsky mine, but by the end of 2021 its value had significantly decreased. The main causes of occupational injuries in coal mines are: unsatisfactory organisation of work and violation of the work schedule and work discipline by employees.

3.2. Risk of occupational diseases

An occupational disease is a disease resulting from prolonged exposure of the human organism to occupational hazards in the course of work activities. In the coal mining sector, there is a high risk of developing occupational diseases, which is associated with harmful working conditions in the workplaces of miners. In the structure of occupational diseases of workers in coal mines there are respiratory diseases, which is associated with the negative impact of industrial aerosols, diseases associated with physical overload, which is associated with the increased severity of work during work operations, vibration diseases, hearing loss, etc. [27, 28].

To calculate the risk of occupational diseases in the coal mining regions of Russia, statistical reporting data were used. The results are shown in Fig. 4. The risks of occupational injuries are presented as a linear correlation. The standard deviation (M) and standard error (SEM) are calculated for each relationship.

Analysis of Fig. 4 shows that the highest risk of occupational diseases is characteristic of the Kemerovo Region, and the lowest risk is observed in the Sakhalin Region, but its value has remained constant over the 10-year period. In general, there is a downward trend in

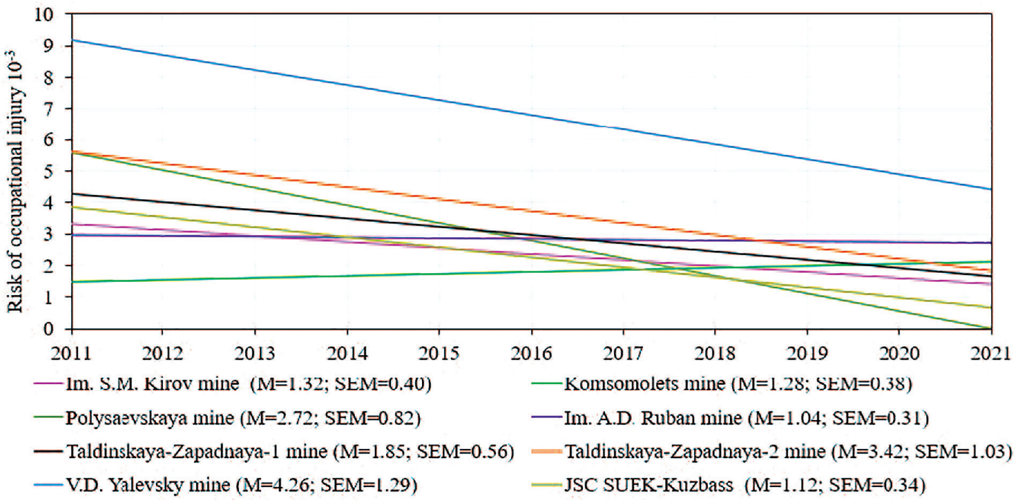

Fig. 3. Risk of occupational injuries at SUEK-Kuzbass mines

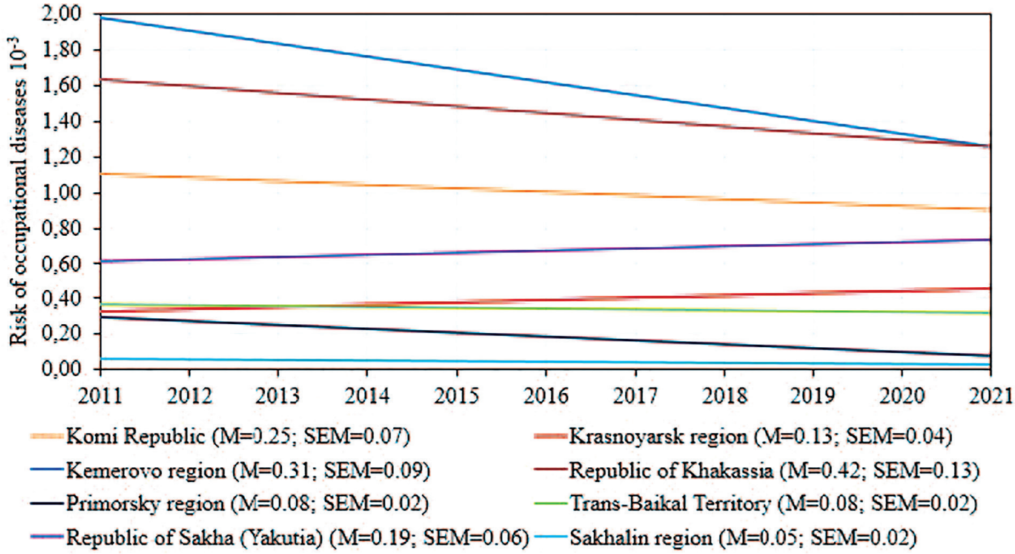

Fig. 4. Occupational diseases risk in coal mining regions of Russia

the risk of occupational diseases in most coal mining regions, with the exception of the Republic of Sakha (Yakutia) and Krasnoyarsk Territory.

Due to the highest risk of occupational diseases in the Kemerovo Region, as well as the highest risk of occupational injuries, this region has received special attention. Fig. 5 shows the dynamics of first-time occupational diseases in Russia and in the Kemerovo Region per 10,000 of the employed population.

It is worth noting that the number of persons with newly identified occupational diseases in the Kemerovo Region is much higher, for example, in 2021, this Fig. was 6.97 per 10,000 employed population, which is 9 times higher than the same Fig. in Russia. Therefore, it is necessary to pay special attention to this problem and consider the identified occupational diseases in more detail [29]. Fig. 6 presents the structure of occupational diseases by various factors in the Kemerovo Region.

Fig. 6 shows that the factor of physical overwork prevails in the structure of detected occupational diseases of miners. The main causes of occupational diseases causing high severity of work are: imperfect technological process, constructive defects of used equipment, violation of technological process, failure to use personal protective equipment and weaknesses in the organization of workplaces [30–32].

3.3. Comparison of occupational injury and diseases risks

For a more detailed assessment of occupational safety in the coal industry, it is advisable to study the correlation of two indicators, such as the risk of occupational injuries and occupational diseases. Fig. 7 shows linear correlations of risks over a 10-year period at coal mining enterprises in the Kemerovo Region.

By analysing the dependencies obtained, we can observe the same trend of risk reduction over a 10-year period. The coefficient of determination for injury risk and occupational diseases risk is 0.823. This means that the calculated model parameters explain the dependence between the studied parameters by 82.3%. For a more detailed analysis, let

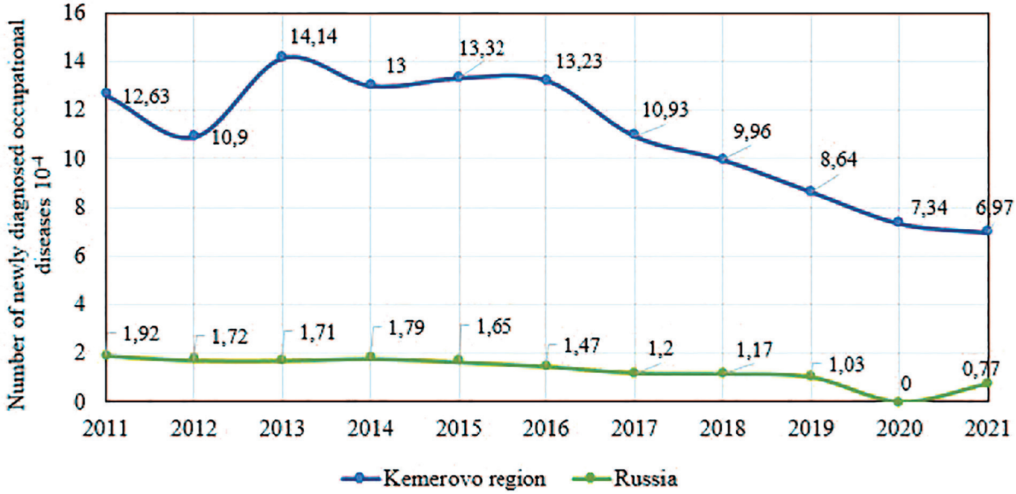

Fig. 5. Dynamics of occupational diseases

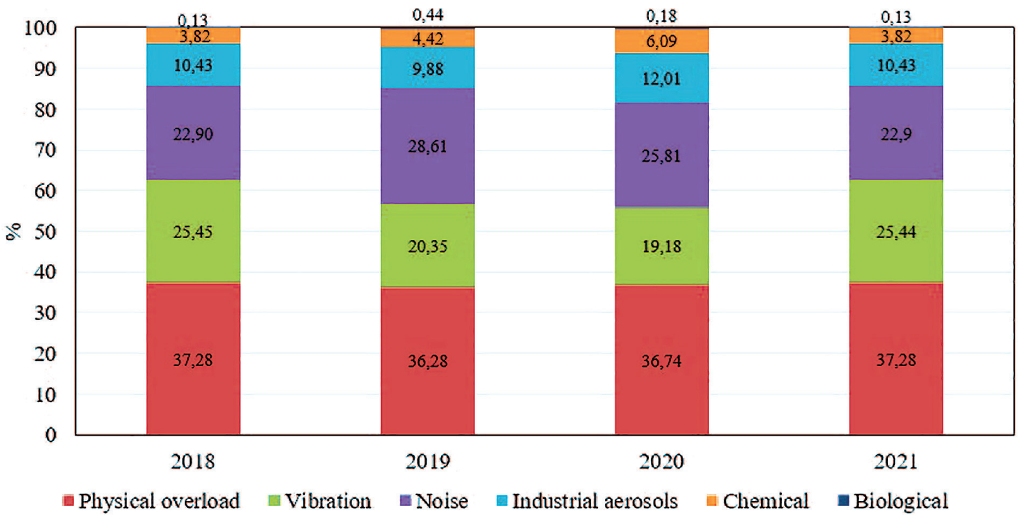

Fig. 6. Structure of occupational diseases by factor in Kemerovo Region

us consider the relationship between these parameters (Fig. 8).

Considering the correlation between injury risk and occupational diseases, a linear relationship is observed with a correlation coefficient of 0.907, which characterises the closeness of a linear correlation relationship between one stochastic variable and some set of stochastic variables, and a positive regression coefficient (Table 1). Thus, over time, the impact of occupational diseases of workers leads to an increase in the risk of occupational injuries.

There is a functional relationship and a probabilistic (stochastic) relationship between the random variables of occupational injury and diseases risk, that is, as one stochastic variable changes, another stochastic variable takes on a corresponding value.

As one of the numerical characteristics of the probabilistic relationship between two stochastic variables X_i, X_j the

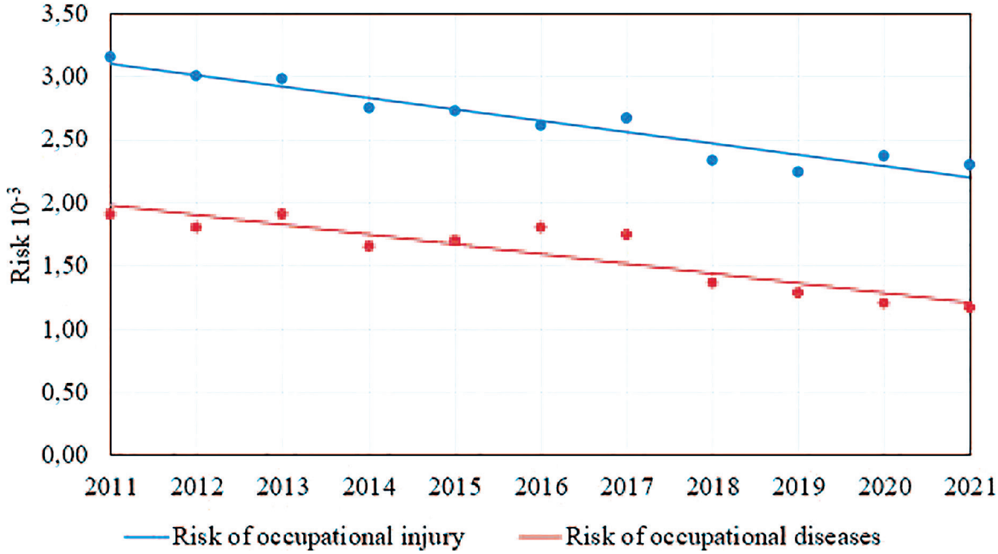

Fig. 7. Linear correlations of occupational injury and diseases risk in the Kemerovo region

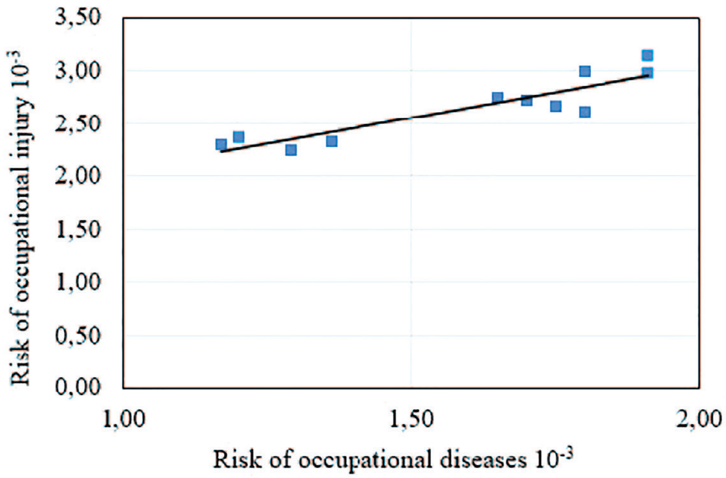

Fig. 8. Dependence of occupational injury risk on occupational diseases

covariance of the stochastic variables is introduced, defined by the formula:

$$\sigma_{ij} = \mathrm{cov}(X_i, X_j) = \\ = M(X_i - MX_i)(X_j - MX_j) \quad (1)$$

or according to the formula

$$\sigma_{ij} = M(X_i \cdot X_j) - M(X_i)M(X_j). \quad (2)$$

If the stochastic variables X_1 and X_2 are independent, then

$$\mathrm{cov}(X_1, X_2) = 0, \quad (3)$$

If $\mathrm{cov}(X_1 X_2) \neq 0$, then the stochastic variables X_1, X_2 are dependent [33, 34].

If there is a sample $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$, for which there is a correlation between two stochastic variables, then the relationship of the stochastic variables can be defined on the x0y coordinate domain, that is, on the correlation field

Table 1
Parameters of a linear regression of the relationship between occupational injury risk and occupational diseases

Regression statistics				
Multiple R	0,90744			
R-square	0,82344			
Normalised R-square	–1,22222			
Standard error	0,13781			
Analysis of variance				
	df	SS	MS	F
Regression	11	0,79718	0,07247	41,97416
Remainder	9	0,17093	0,01899	
Total	20	0,96811		

If the sample size is small, the estimate of the correlation characteristics is calculated from the sample data using the formulas [35]:

estimates of first moments of stochastic variables

$$\overline{x} = \frac{1}{n}\sum_{j=1}^{n} x_j,\ \overline{y} = \frac{1}{n}\sum_{j=1}^{n} y_j; \quad (4)$$

estimates of second moments of stochastic variables

$$\hat{\sigma}_X^2 = \frac{1}{n}\sum_{j=1}^{n}(x_j - \overline{x})^2,\ \hat{\sigma}_Y^2 = \frac{1}{n}\sum_{j=1}^{n}(y_j - \overline{y})^2,$$

$$\hat{\mathrm{cov}}(X,Y) = \frac{1}{n}\sum_{j=1}^{n}(x_j - \overline{x})(y_j - \overline{y}). \quad (5)$$

Looking at the relationship shown in Fig. 8, the covariance of the stochastic variables of occupational injury and diseases risks is 0.0801, which proves the dependence of the indicators in question.

This dependence is explained by the fact that in coal mining a large number of harmful factors, such as high dust, noise, vibration, physical overloading, etc., are applied to humans [36–39]. All these factors lead to deterioration of health, loss of ability to work, and subsequently to occupational diseases. There are also many occupational hazards at work, exposure to which can lead to acute poisoning, sudden deterioration of health, injury or death. Working in coal mines for an extended period of time and constant exposure to hazardous and harmful industrial factors weaken the human organism. In this connection, the increased physical strain leads to a reduced reaction of the employee to hazards that arise in the external environment, so that the person is not able to counteract the threats to life and health that arise in the work process in a timely manner.

4. Conclusion

Based on regression-correlation analysis of risk statistical data in coal mining regions of Russia, it was revealed that occupational injury and diseases risks have the highest value in the Kemerovo Region. At the same time, the risk of occupational injuries in the 10-year period at coal mining enterprises in Kuzbass decreased by 27%, with its average value for that period being 0.0027. In turn, the risk of occupational diseases decreased by 38.5%, with its average value for the period being 0.0016.

When comparing the risks of injuries and occupational diseases, a linear relationship with a correlation coefficient of 0.907 was observed, that is, it can be noted that over time, the impact of occupational diseases of workers leads to an increase in the risk of occupational injuries. This phenomenon is explained by constant exposure to harmful and dangerous factors in the process of work activity of miners and its cumulative impact on the risk of health damage.

The calculated covariance of the stochastic values of occupational injury and diseases risks was 0.0801, indicating that there is a correlation between the indicators in question.

Thus, a comprehensive approach is needed to improve occupational safety at coal mining companies. Continuous improvement of the occupational safety system, analysis of the risks of occupational injuries and occupational diseases, as well as increasing the motivation of employees to work safely.

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