IRSTI 68.03.01
Section: Ecology
Article

Assessment of the impact of local vibration on the health of workers in the mining industry of East Kazakhstan

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Abstract: This work is dedicated to the study of impact of local vibration on the health of miners in the East Kazakhstan region, where mining industry is one of the leading sectors of the economy and a major source of employment. Vibration disease is one of the most common occupational diseases among workers who use vibration-prone equipment on a regular basis. Vibration, combined with other harmful factors such as industrial noise, poor microclimate, and heavy physical loads, negatively affects workers' health and significantly contributes to the development and progression of vibration pathology. The study used mathematical modeling methods to analyze the relationship between vibration dose, exposure time, and the body's physiological response. Special attention was given to eco-rehabilitation measures aimed at improving working conditions and reducing the risks of occupational diseases in hazardous environments. The work presents practical recommendations for organizing effective protective measures for workers, including compliance with sanitary and hygienic standards, reducing vibration exposure, conducting regular preventive medical examinations, and improving the occupational medical care system. The results of the study can be used to develop and implement new standards and recommendations for the mining industry to improve working conditions and protect the health and long-term well-being of miners.

Keywords: local vibration; vibration disease; mining industry; occupational diseases; workers' health; prevention.

Citation: Nurzhan, G., Sadykanova, G., Kumarbekuly, S., Alipina, K., Igissinova, Zh. (2025). Assesstment of the impact of local vibration on the health of workers in the mining industry of East Kazakhstan. Bulletin of the L.N. Gumilyov ENU. Chemistry. Geography. Ecology Series, 152(3), 207-221. https://doi.org/10.32523/2616-6771-2025-152-3-207-221

Academic Editor:
Zh.G. Berdenov

Received: 05.05.2025
Revised: 08.09.2025
Accepted: 15.09.2025
Published: 30.09.2025

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1. Introduction

Occupational health and safety in the mining industry remain a significant concern in modern industrial production. One of the major risk factors is exposure to local vibration, especially from mechanized hand tools.

Vibration disease is among the most common occupational illnesses, accounting for approximately 80.5% of all cases linked to hand-held tool use (Zimmerman et al., 2024).

Scientific interest in the health effects of vibration dates back to 1911, when Loriga first described the clinical symptoms caused by pneumatic tools (Coggon, 2022). Later, Walsh et al. (2019) proposed a dose-based evaluation system for protective measures (Walsh et al., 2019).

In recent decades, deteriorating socio-economic and healthcare conditions - particularly in urban areas like Moscow - have exacerbated health risks (Shastin et al., 2021). For example, in the UK, over 2 million people report work-related illnesses, with 0.5 million suffering from chronic stress. National initiatives promote healthy workplaces, rehabilitation, and early diagnostics (Ljandres et al., 2000; Alekseev & Janushanec, 2002; Izmerov, 2012; Trumel', 2002; Maljutina & Eremeev, 2003).

According to Eurostat and the 2nd European Working Conditions Survey, occupational morbidity is increasing across Europe (Barnay, 2016). In Russia, Retnev V.L. reports that long-term exposure to physical and environmental stressors remains the main cause of occupational illness. Annually, Russia registers 10,000–11,000 cases, while the U.S. reports around 200,000, with an estimated economic burden of $40 billion. The UK has integrated health and safety into its business frameworks (Nurzhasarova, 2007; Lebedev et al., 2002).

Between 2019 and 2024, the number of registered occupational diseases in Russia increased from 9,280 to 57,710, although official rates remain 30–45 times lower than in developed countries due to differing diagnostic standards (Zenkov, 2002; Oleshhenko et al., 2002).

In the coal mines of Kuzbass, disease incidence exceeds the regional average by 3.5 times, reaching 12.9 per 10,000 workers. Most common diagnoses include musculoskeletal disorders (48%), hearing loss (22.2%), and vibration disease (16.2%) (Amanbekov et al., 2002). In Ukraine, vibration disease accounted for 61.8% of occupational illnesses among miners (2019–2021), with physical overstrain contributing 9.7% (Farrell et al., 2020).

In low-mechanized mines, occupational illness is caused by intense vibration, dust, noise, and high workload (Muhin & Solov'ev, 2001). Even in mechanized enterprises, over 63% of cases are related to musculoskeletal and nervous system disorders (Walker-Bone et al., 2002). A comparative study involving 2,245 patients from 24 professions confirmed the significant role of regional muscle overload (Moellering et al., 2023).

Conditions such as polyosteoarthrosis, spondylosis, radiculopathy, and osteochondrosis are most prevalent among workers aged 45–65, especially with genetic predisposition and prolonged physical load.

Professional breakdown shows coal miners (32%), tunnelers (22.2%), repair workers (12.5%), machine operators (6.8%), electricians (5.6%), engineers/technicians (6.5%), and other professions (14.4%) (Farbtuh et al., 2002). Notably, 84% of miners work in Class III hazardous conditions, with 34.3% in levels 3–4. In Smolensk, 75% of illnesses are attributed to vibration, noise, and strain.

Modern occupational illnesses are increasingly multifactorial, combining vibration, overload, and microclimate impacts, with 70% of cases involving comorbid pathologies (e.g., musculoskeletal and vibration-related) (Samanta et al., 2023).

Theoretical modeling and socio-economic analysis of comorbid illnesses are key research priorities. In Kemerovo, up to 1,500 workers are declared disabled annually due to occupational diseases, with 60% from the coal industry. In Anzhero-Sudzhensk, 29% of patients have 2–3 diagnoses. Despite industrial decline, morbidity remains high (Shastin et al., 2019).

In Latvia, from 2019 to 2021, the average number of diseases per case was 2.2. In Donetsk, cardiovascular and musculoskeletal disorders dominate. In Kazakhstan, the highest risk regions are Karaganda, Zhezkazgan, East Kazakhstan, and Pavlodar, with illness prevalence rising among workers with over 15 years of experience.

This research is aimed at analyzing the structure, prevalence, and causes of occupational diseases associated with vibration exposure among workers in the mining industry of Kazakhstan and selected CIS countries.

The study focuses on identifying key vibrational, physical, and ergonomic factors contributing to the development of occupational pathologies. Particular emphasis is placed on the correlation between working conditions (including duration of exposure, intensity of vibration, and combined action of harmful factors) and the incidence of disorders affecting the musculoskeletal and nervous systems. In addition, the study assesses the effectiveness of preventive and protective measures aimed at mitigating occupational health risks.

It is hypothesized that chronic multifactorial exposure to vibration, physical overload, and industrial noise exerts a cumulative and systemic effect on the health of mining personnel. This effect is especially pronounced among workers with long-term exposure and limited access to medical surveillance.

2. Materials and methods

Object of the study: Industrial mining enterprises in Kazakhstan (including the Ridder Mining and Processing Plant), Kuzbass (Russia), and Donbas (Ukraine).

Subject of the study: Occupational morbidity associated with local vibration, noise, and physical overload in high-risk mining occupations.

Data sources and research tools:

- Official statistics from the Ministry of Health of the Republic of Kazakhstan, the National Center for Occupational Pathology, Rosstat (Russia), Eurostat, and WHO reports;
- Archival data on occupational disease incidence (2000–2024);
- National and international legal documents and sanitary norms (e.g., SNIP, GOST, ISO standards);
- Clinical reports and diagnostic data (functional, neurological, and imaging examinations) from occupational health centers.

Analytical methods:

- Content analysis of regulatory frameworks and labor protection laws;
- Comparative method for interregional and international comparison of disease prevalence and risk factors;
- Descriptive and inferential statistical analysis using SPSS Statistics 26.0, including correlation, regression, and trend analysis;
- Graphical visualization and structural mapping with Microsoft Excel and Tableau Public;
- Synthesis of clinical results, including data from electromyography, radiographic imaging, and cardiovascular functional tests.

Stages of the study:

1. Collection and verification of statistical, clinical, and legal data (2000–2024);
2. Quantitative analysis of the structure and dynamics of occupational morbidity in the mining sector;
3. Identification of regional and professional risk factors, including duration of exposure and workplace conditions;
4. Comparison of international preventive practices and implementation models in occupational health;
5. Formulation of recommendations for risk assessment, prevention, and mitigation strategies in the mining sector.

3. Results

3.1 Clinical characteristics of vibration disease

When determining the severity of vibration disease, researchers take into account the degree of expression of vegetative-vascular, trophic, sensory, motor, and reflex disorders.

Vibration disease of the first degree is marked by early symptoms, including:

- Peripheral angiodystonic syndrome;
- Angiodystonic syndrome with intermittent acrospasms of the fingers;

- Sensory polyneuropathy of the hands. The early symptoms include mild pain and paresthesia in the limbs, slight acrocyanosis of the fingers, capillary spasms up to the wrist joint, reduced vibrational sensitivity, and mild functional disorders of the central nervous system.

Vibration disease of the second degree is characterized by moderately pronounced symptoms, including:

- Peripheral angiospastic syndrome with frequent acrospasms and chronic vegetative-trophic disorders;
- Sensory polyneuropathy with dystrophic changes in the musculoskeletal system and polyradicular disturbances.

In these cases, pain and paresthesia become constant, the polyneuritic type of disorder spreads to the hand and forearm, accompanied by reduced vibrational sensitivity, acrocyanosis of the hands, and whitening of the fingers. Functional disorders of the nervous system, such as neurasthenia syndrome and cardialgia, are also observed.

Vibration disease of the third degree is characterized by pronounced manifestations:

- Sensomotor polyneuropathy syndrome;
- Generalized angiospastic syndrome with polyneuropathy.

Vegetative-vascular and trophic disorders become persistent, with thermosymmetry, capillary atony, and arterial hypertension syndrome. Sensory disturbances become more persistent and may be segmental in nature. Vibrational sensitivity decreases or disappears.

Pronounced asthenoneurotic states are accompanied by increased reflexes, eyelid and finger tremors. Vestibulopathy and disorders of endocrine and metabolic processes are often observed. Cardiac dysfunction becomes persistent, and myocardial dystrophy is detected on the ECG.

3.2 Subjective assessment of working conditions

The questionnaire method was applied to assess the working conditions of 32 miners, with attention to the severity and intensity of labor processes. The survey revealed a diverse range of responses concerning factors perceived to influence performance in underground mining operations.

More than one-third of the respondents (38.7%) attributed decreased performance to the heaviness of the work, with 47.0% noting it as a primary factor. Among tunneling miners, 55.1% reported that dust exposure hindered the completion of production tasks. The next most frequently cited factors were the heaviness of the work (48.6%) and high air humidity (32.3%).

Support workers, engaged in particularly demanding physical activities, primarily associated reduced performance with the heaviness of the work (69.7%) and the effects of vibration (24.7%). For underground electricians, the main limiting factors were the heaviness of the work (26.6%) and elevated humidity levels (24.3%).

Additionally, 46.1% of miners linked their work efficiency to increased strain on sensory systems, while heaviness of labor, vibration, and cooling microclimate conditions were commonly perceived as hindrances to productivity (Table 1).

Table 1. Subjective assessment of working conditions by miners in underground mines, %

Questions	**Answer options**	**Mining face workers**	**Tunneling miners**	**Support workers**	**Underground electrical fitters**	**χ^2 / p-value**
Assessment of Working Conditions	Good	31.25	21.67	21.4	24.8	$\chi^2 = 6.54$, $p = 0.011$
	Satisfactory	46.8	45.18	43.1	45.1	
	Bad	21.95	33.15	35.5	30.1	
Total:		100	100	100	100	
Have the working conditions	Improved	14.3	13.7	11.3	15.2	$\chi^2 = 4.28$, $p = 0.042$
	Worsened	21.2	19.4	23.3	20.4	
	Remained	64.5	66.9	65.4	64.4	

changed in the last few years (2020-2024)	unchanged					
Total:		100	100	100	100	

Note: Values are presented as percentages of respondents (n = 32). Statistical significance was assessed using the chi-square test for categorical data. p < 0.05 () was considered statistically significant.

Figure 1 presents the subjective assessment of the impact of mining industry factors on the health of miners, expressed as a percentage of respondents who identified specific risk factors.

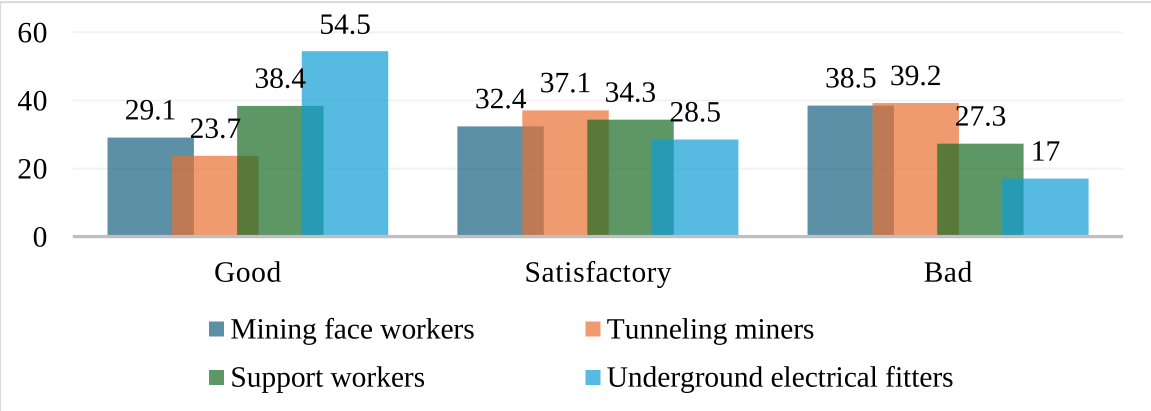

Figure 1. Subjective assessment of the impact of mining industry factors on the health of miners, (% of respondents, n = 32).

Data are presented as percentages for four occupational groups: mining face workers, tunneling miners, support workers, and underground electrical fitters.

3.3 Hygienic standards of vibration

For comparison with the obtained results, hygienic standards for vibration were used according to the Sanitary and Epidemiological Requirements No. 310 (Ministry of Health of the Republic of Kazakhstan, 2005). Tables 2 and 3 present the hygienic standards for vibration and the maximum allowable values of local vibration parameters along the axes Z, X, and Y, respectively. These reference values are presented in Tables 2 and 3.

Table 2. Hygienic standards for vibration

Type of Vibration	**Maximum allowable vibration velocity level, dB, in octave bands with mean geometric frequencies, Hz**										
	1	2	4	8	16	31,5	63	125	250	500	1000
General transport vertical horizontal	132 132	123 117	114 116	108 116	107 116	107 116	117 116	-	-	-	-
Transport-technological	-	117	108	102	101	101	101	-	-	-	-
Technological	-	108	99	93	92	92	92	-	-	-	-
In production rooms where there are no machines generating vibration	-	100	91	85	84	84	84	-	-	-	-

In service rooms, medical points, design offices, and laboratories	-	91	82	76	75	75	75	-	-	-	-
Local vibration	-	-	-	115	109	109	109	109	109	109	109

Table 3. Maximum allowable values of local vibration parameters along the axes Z, X, and Y

Mean geometric frequencies of octave bands, Hz	**Vibration acceleration**		**Vibration velocity**	
	m/s^2	dB	$m/s \times 10^{-2}$	dB
8	1.4	123	2.8	115
16	1.4	123	1.4	109
31.5	2.8	129	1.4	109
63	5.6	135	1.4	109
125	11.0	141	1.4	109
250	22.0	147	1.4	109
500	45.0	153	1.4	109
1000	89	159	1.4	109
Corrected and equivalent corrected values and their levels	2.0	126	20.0	112

Source: Ministry of Health of the Republic of Kazakhstan (2005).

3.4 Prevalence of vibration disease

The data on the number of patients analyzed for vibration disease, categorized by severity, age, and experience, are shown in Figure 2.

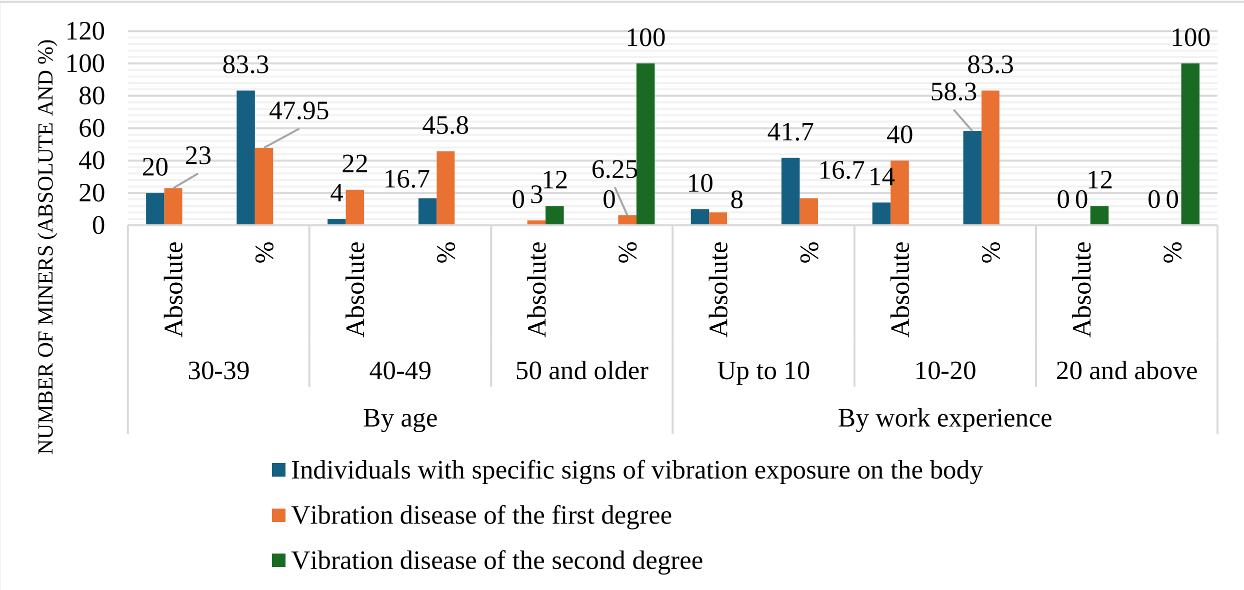

Figure 2. Distribution of patients with vibration disease by severity, age, and work experience (absolute numbers and %, descriptive statistics)

3.5 Mathematical modeling of vibration impact

A mathematical model was developed to assess the «dose–time–effect» relationship of vibration exposure among miners. Figures 3-7 illustrate the progression of physiological response depending on dose level and exposure time.

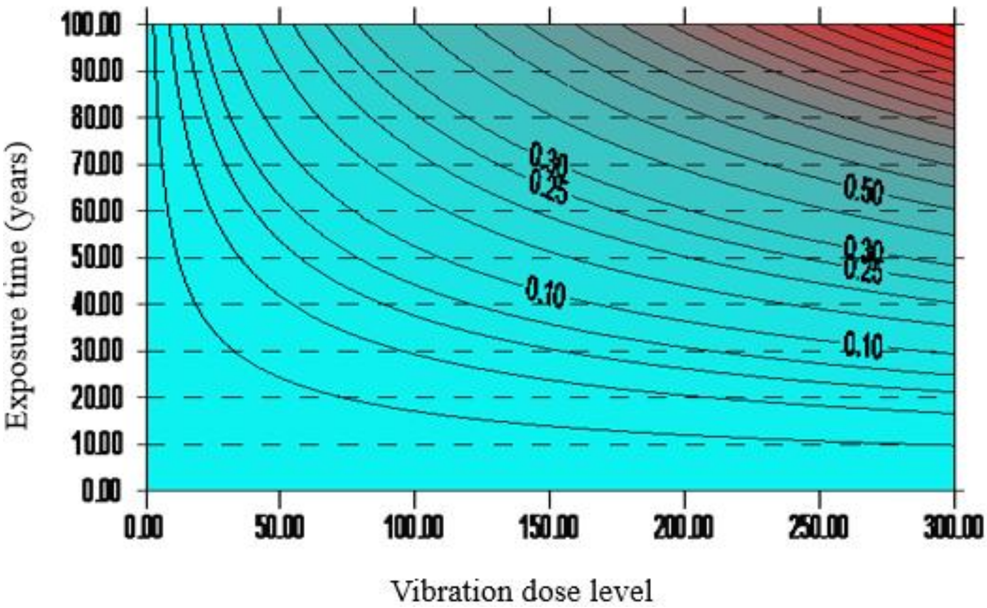

Figure 3. Mathematical model of the «dose–time–effect» relationship of vibration exposure, showing the dependence of exposure time (years) on vibration dose level

A fragment of the construction of the mathematical model is shown below in Figure 4.

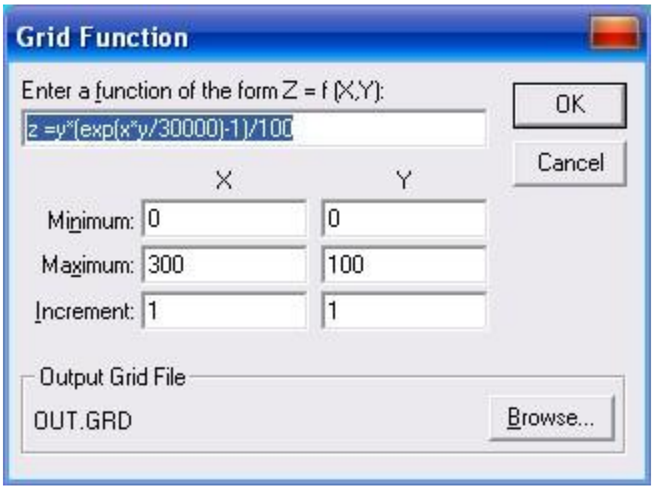

Figure 4. Fragment of the construction of the mathematical model

$$E = \tilde{d} * \left(exp\left(\tilde{t} * \tilde{d}\right) - 1\right) \quad (1)$$

where E - effect
- scalable dose;
- scalable time;
The scalable dose and time are defined as follows:

$$\tilde{d} = d/D^*$$

and accordingly

$$\tilde{t} = t/T^*$$

where D^* и T^* - are the maximum dose and maximum work experience, respectively

The following values for the dose and time parameters were used in the above-mentioned graphs: T^{*}= 25 years = 300 months, D^{*}=1000 Hz

Figure 5 shows the cumulative effect of vibration exposure at fixed doses over the maximum time period.

$$E = \sum_{i=1}^{N} E_i \qquad (2)$$

where E - the effect obtained at a fixed dose, and - the N maximum time.

$$E_i = \tilde{d}_i * \left(exp\left(\tilde{t} * \tilde{\tilde{d}}_i\right) - 1\right) \qquad (3)$$

Figure 5. Cumulative effect achieved over the maximum duration

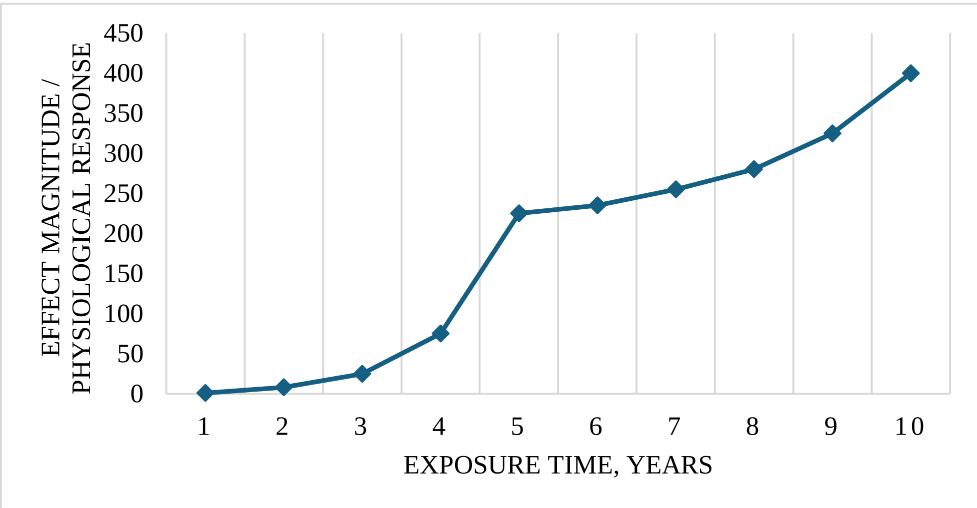

Figure 6. «Dose - time - effect» relationship

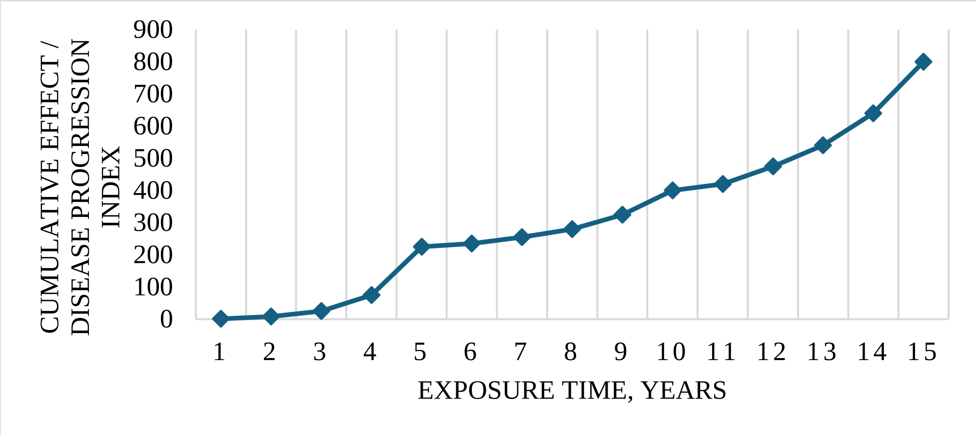

Figure 7. Continuation of the «dose - time - effect» relationship

4. Discussion

Vibration exerts multisystem effects through mechanical transmission and neuroreflex pathways. Its biological impact depends on frequency and intensity, affecting vascular tone and peripheral nerve function.

Our findings confirm the critical involvement of both central and peripheral nervous systems in the development of vibration disease. Notably, dysfunction of the sympathetic nervous system, which regulates vascular tone, is consistent with earlier reports by Grassi et al. (2015) and Bruno et al. (2012). Sensory disturbances - including reduced vibrational sensitivity and paresthesia - increase in severity proportionally with exposure duration and intensity, supporting the dose–time–effect relationship demonstrated in Figures 3–7.

It is known that low-frequency vibrations (4-11 Hz) particularly impair coordination and psychomotor functions, consistent with the observations of Matsumoto and Griffin (2002). Moreover, female workers are at increased risk of gynecological complications under chronic vibration exposure, as noted by Skröder et al. (2020).

Despite ongoing technological modernization, vibration disease remains prevalent in the mining sector, especially in areas using outdated equipment or lacking adequate hygienic oversight. This is corroborated by our survey (Table 1), where over 30% of miners assessed their working conditions as poor, citing vibration, high workload, and inadequate microclimate as key hindering factors. These findings align with Sharipova (2015), who emphasized the negative consequences of declining workplace healthcare infrastructure in Kazakhstan.

Our mathematical model of the «dose–time–effect» relationship (Figures 3–7) demonstrates that exceeding vibration exposure thresholds leads to accelerated onset of pathological conditions. The model enables estimation of individual risk levels based on specific exposure parameters, supporting the development of early preventive measures.

However, the study has certain limitations. It was conducted at a single mining site, and longitudinal monitoring was not performed. These factors limit the generalizability of our findings. Future research should include multi-site longitudinal studies and explore biological markers of sensitivity to vibration, as well as the effectiveness of intervention and rehabilitation strategies.

In summary, vibration remains a significant occupational hazard with wide-ranging effects on workers' health and performance. Predictive modeling may serve as a practical tool for early risk identification and enhance hygiene regulations and medical protocols.

Table 1 presents the results of a questionnaire survey conducted among 32 miners, which assessed their subjective evaluation of working conditions in underground mines. The table reflects differences among specific occupational groups - such as tunneling miners, support personnel, and underground electricians - in how they perceive factors like work heaviness, dustiness, air humidity, and exposure to vibration. These data reveal considerable variation in the perceived impact of working conditions depending on the nature of the tasks performed.

At the current stage of scientific and technological progress, improving working conditions, living standards, and medical services plays an essential role in occupational health. In this regard, a hygienic survey was conducted among miners to collect data for the development of health-improving measures. A questionnaire was used to gather information on miners' subjective assessments of their health status. The results, presented in Figure 1, reveal significant differences in how workers perceive the impact of various mining-related factors on their health.

Mining is classified as heavy physical labor and involves significant dynamic muscle strain. According to the results, 88% of miners are employed under Class III hazardous working conditions, with 54.4% working in levels III.3 and III.4 - environments characterized by exposure to vibration, poor microclimate, and physical overload.

Our analysis confirms that task performance quality is influenced by the degree of mechanization of labor-intensive operations and the intensity of adverse workplace factors. Miners' work remains associated with unmechanized and monotonous tasks, exposure to cold and heat, vibration, and psycho-emotional stress, all of which contribute to accelerated development of occupational pathologies.

Risk assessment of exposure to physical factors - particularly local vibration - is essential in preventing occupational diseases. When hygienic standards are exceeded, both occupational and general somatic illnesses may develop.

As noted by Kulkybaev G.A., the deterioration of occupational healthcare - including the elimination of shop physician positions - has led to reduced effectiveness in prevention and early detection of occupational diseases. The low quality of periodic medical examinations results in late diagnosis and growing numbers of workers with occupational disabilities.

Further study of the pathogenesis of vibration-related disorders and the development of rehabilitation strategies are urgently needed, especially given the limited current understanding of the «dose–time–effect» relationship. This relationship forms the foundation for reliable risk assessment and disease forecasting.

Regulatory documents, including the *Sanitary and Epidemiological Requirements for Working Conditions with Vibration Sources* No. 310 (2005), define permissible exposure levels. These standards regulate vibration exposure within specific frequency bands: 16, 31.5, 63, 125, 250, 500, and 1000 Hz for an 8-hour shift. Hygienic limits for different vibration types and frequencies are summarized in Tables 2 and 3.

Additionally, health records from the Ust-Kamenogorsk Occupational Pathology Clinic were analyzed for 84 miners diagnosed with vibration disease of varying severity. These miners, primarily tunneling workers and drill operators from the Ridder mining and processing plant, were examined at the Research Institute of Hygiene and Occupational Diseases (Ministry of Health, Republic of Kazakhstan).

As illustrated in Figure 2, most patients (48 individuals, 57.2%) were diagnosed with first-degree vibration disease, while 24 individuals (28.6%) exhibited early signs of vibration-related pathology. Only 14.2% (12 individuals) were diagnosed with second-degree vibration disease, confirming that early detection remains feasible with proper monitoring and workplace screening.

The model presented in Figure 4 demonstrates the «dose - time - effect» relationship, where the horizontal curves illustrate the probability of the miner's physiological response depending on vibration exposure and the development of vibration pathology.

From the obtained data, it can be concluded that as the vibration dose increases, the time for the effect to occur from exposure to this physical factor decreases.

As shown in Figure 5, this curve represents the physiological response of a worker engaged in the drilling process with a short work experience (up to 5 years) when using equipment that generates vibration at doses corresponding to the maximum permissible level (MPL) of 109 dB. At a vibration frequency of up to 250 Hz, which also corresponds to the MPL of local vibration, a sufficient physiological response occurs after 5 years of work experience.

As shown in Figure 6, after a certain period (5–8 years), with an increase in vibration dose, the physiological resources of the body become depleted, and performance decreases. At a vibration dose with a frequency of 300 Hz (130 dB), a physiological response may appear after approximately 3.5 years of exposure, which can lead to the development of vibration disease.

As shown in Figure 7, the model reflects the continuation of the «dose–time–effect» relationship, where negative processes in the body accumulate and intensify with the depletion of physiological resources. When exposed to a physical factor with a frequency of 400 Hz (174 dB), the body may begin to respond after only 2 years of exposure. On the one hand, as the vibration dose increases, the time required for the manifestation of negative physiological effects and the development of vibration disease decreases. On the other hand, with increasing work experience in vibration-producing occupations, the dose load tends to decrease. Thus, based on the results of the mathematical modeling (Figures 3, 5, 6, and 7), the impact on the human body can be assessed in terms of both vibration intensity and duration of exposure.

5. Conclusion

The mining industry remains a strategic sector of the economy in the Republic of Kazakhstan; however, it is associated with intense physical labor and exposure to harmful occupational factors, particularly vibration. The specific geological conditions and outdated equipment used at mining enterprises create an environment that exceeds sanitary and hygienic standards, significantly increasing the risk of developing occupational diseases, especially vibration pathology.

The study confirms that the incidence of vibration disease among miners in East Kazakhstan remains high, reaching 52.6%, with the onset of symptoms observed as early as 8 years into employment. As vibration levels rise, the time for clinical manifestation shortens from 5 to 2 years. The critical exposure period of 5–8 years serves as a threshold for the onset of pathological changes. Furthermore, as experience increases, the cumulative dose tends to decrease, suggesting that physiological adaptation or workforce attrition may play a role.

Vibration pathology remains prevalent among miners, with disease onset observed after 8 years of exposure.

Preventive strategies include limiting exposure duration, providing scheduled breaks, improving tool design, maintaining optimal microclimate, and ensuring regular medical checkups.

However, the current socio-economic context complicates effective prevention. Economic instability, reduction of workplace medical units, and limited access to occupational health services contribute to workers’ reluctance to seek timely medical attention. As a result, many continue working despite clear signs of occupational illness.

The study highlights the urgent need for systemic reforms in occupational health management, modernization of equipment, and restoration of preventive medical services in the mining industry. Further longitudinal studies involving larger and more diverse worker populations are needed to refine predictive models and develop targeted interventions. Addressing these issues is essential for safeguarding the health and productivity of Kazakhstan’s mining workforce.

6. Supplementary Materials: No supplementary materials.

7. Author Contributions

Conceptualization, methodology, validation, data curation, formal analysis, investigation, resources, writing-original draft preparation - G.N., G.S., S.K.; data curation, writing-review and editing, supervision - K.A., Zh.I. All authors have read and agreed to the published version of the manuscript.

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9. Funding: This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant № AP23489325).

10. Acknowledgements: The authors have no additional acknowledgments to report.

11. Conflicts of Interest: The authors declare no conflicts of interest.

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Шығыс Қазақстанның тау-кен өнеркәсібі жұмысшыларының денсаулығына локалды вибрацияның әсерін бағалау

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Андатпа. Бұл жұмыс Шығыс Қазақстан өңіріндегі тау-кен өндірісінде еңбек ететін кеншілердің денсаулығына локалды вибрацияның әсерін зерттеуге арналған. Тау-кен өнеркәсібі - өңір экономикасының жетекші салаларының бірі және халықты жұмыспен қамтудың маңызды көзі болып табылады. Вибрациялық ауру - вибрацияға ұшырайтын құрал-жабдықтармен үнемі жұмыс істейтін жұмысшылар арасында ең жиі кездесетін кәсіптік аурулардың бірі. Вибрация өндірістік шу, қолайсыз микроклимат және ауыр физикалық жүктеме сияқты басқа да зиянды факторлармен қатар жұмысшылардың денсаулығына теріс әсер етіп, вибрациялық патологияның дамуы мен өршуіне елеулі үлес қосады. Зерттеу барысында вибрация дозасы, әсер ету уақыты мен ағзаның физиологиялық жауабы арасындағы байланысты талдау үшін математикалық модельдеу әдістері қолданылды. Қауіпті өндірістік ортада еңбек жағдайларын жақсарту және кәсіби аурулар қаупін азайту мақсатында экологиялық сауықтыру шараларына ерекше көңіл бөлінді. Жұмысшыларды қорғаудың тиімді шараларын ұйымдастыруға арналған практикалық ұсыныстар ұсынылды, оның ішінде санитарлық-гигиеналық талаптарды сақтау, вибрациялық әсерді азайту, тұрақты профилактикалық медициналық тексерулер жүргізу және кәсіби медициналық қызмет жүйесін жетілдіру қамтылған. Зерттеу нәтижелері тау-кен өнеркәсібінде еңбек жағдайларын жақсартуға және кеншілердің денсаулығы мен ұзақ мерзімді еңбекке жарамдылығын сақтауға бағытталған жаңа стандарттар мен ұсынымдарды әзірлеуге және енгізуге пайдаланылуы мүмкін.

Түйін сөздер: локалды вибрация; вибрациялық ауру; тау-кен өндірісі; кәсіби аурулар; жұмысшылардың денсаулығы; профилактика

Оценка воздействия локальной вибрации на здоровье работников горно-рудной отрасли Восточного Казахстана

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Аннотация: Данная работа посвящена изучению воздействия локальной вибрации на здоровье шахтёров Восточно-Казахстанского региона, где горнодобывающая промышленность является одной из ведущих отраслей экономики и важным источником занятости населения. Вибрационная болезнь - одно из наиболее распространённых профессиональных заболеваний среди работников, регулярно использующих оборудование, подверженное вибрации. Воздействие вибрации в сочетании с другими вредными факторами, такими, как производственный шум, неблагоприятный микроклимат и высокая физическая нагрузка, отрицательно сказывается на здоровье работников и в значительной степени способствует развитию и прогрессированию вибрационной патологии.

В исследовании использовались методы математического моделирования для анализа взаимосвязи между дозой вибрации, временем воздействия и физиологической реакцией организма. Особое внимание было уделено мерам эко-реабилитации, направленным на улучшение условий труда и снижение рисков профессиональных заболеваний в условиях вредного производства.

Работа содержит практические рекомендации по организации эффективной системы защиты работников, включая соблюдение санитарно-гигиенических норм, снижение уровня вибрационного воздействия, проведение регулярных профилактических медицинских осмотров и совершенствование системы профессионального медицинского обслуживания. Полученные результаты могут быть использованы при разработке и внедрении новых стандартов и рекомендаций для горнодобывающей отрасли с целью улучшения условий труда, сохранения здоровья и работоспособности горняков.

Ключевые слова: локальная вибрация; вибрационная болезнь; горнодобывающая промышленность; профессиональные заболевания; здоровье работников; профилактика