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A Study on Causal Relationships Between Working Conditions and Occupational Diseases: A Case Study of a Phosphorus Plant in Kazakhstan

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ABSTRACT

This article examines the relationship between working conditions and the development of work-related diseases at a phosphorus plant. An analysis of occupational risks was conducted based on indicators of relative risk (RR) and etiologic fraction (EF), using data from medical examinations, temporary disability morbidity, and working conditions assessments. The study involved 1,162 workers, of whom 1,021 comprised the experimental group (employees from five workshops of the phosphorus plant exposed to harmful factors), and 141 formed the control group, with no exposure to hazardous occupational factors. By comparing the levels of morbidity, injury, and occupational pathology between these groups, significant differences were found in the levels of risk and the degree of professional conditioning of diseases. The analysis revealed that the highest levels of occupational risk were identified in Workshop No. 12 (RR=4.3; EF=76.7%) and Workshop No. 5 (RR=2.5; EF=60.64%), indicating a strong occupational attribution of the detected pathologies, primarily affecting the sensory and respiratory systems. A moderate level of risk was established in Workshop No. 7 (RR=1.6; EF=37.5%) and was predominantly associated with musculoskeletal disorders. In contrast, Workshops No. 2 (RR=1.1; EF=9.1%) and No. 1 (RR=0.7; EF=–42.9%) demonstrated low risk levels, suggesting a weak or negligible association between working conditions and workers' health outcomes. Models were constructed to show the relationship between RR, the number of cases, and the etiological fraction, reflecting the contribution of production factors to the development of occupational pathology. Strongly significant correlations were found between the impact factors (noise, dust, chemicals) and the morbidity rates of workers. A strong positive correlation was established between the level of inorganic dust (quartzite) and the frequency of upper respiratory diseases ($r=0.97$, $p<0.01$), as well as between dust from inorganic materials (coke, phosphate, gypsum) and the frequency of upper respiratory diseases ($r=0.84$, $p<0.01$). The correlation between noise levels and sensory diseases ($r=0.40$, $p<0.05$) confirmed the impact of physical factors on workers health. Based on the obtained results, a matrix for assessing working conditions was developed, taking into account the new classification of harmful factors proposed in Kazakhstan. The results presented can be used for the prevention of occupational diseases and the optimization of working conditions at industrial enterprises.

1. INTRODUCTION

Forecasting working conditions and associated occupational diseases is an important direction in occupational safety management. This is particularly relevant for chemical industry enterprises, such as phosphorus plants, where exposure to harmful substances and unfavorable production factors can lead to severe health disorders and premature loss of work capacity.

Occupational diseases remain one of the leading causes of loss of work capacity and premature mortality, especially in industrialized countries. According to the International Labour Organization, over 2.7 million cases of work-related deaths and about 160 million new cases of diseases are registered annually [1].

In modern conditions, occupational safety requires a systematic and scientifically justified approach to identifying and managing occupational risks. The foundation for such approaches is evidence-based occupational medicine, which involves an objective assessment of the causal relationship between the impact of production environment factors and the development of diseases, both occupational and work-related [2].

Historically, the prevention of occupational diseases has been based on sanitary-hygienic control of working conditions, sanitary-epidemiological expertise, and regulatory regulation. However, in recent decades, there has been a shift in global practice towards a risk-oriented approach, based on forecasting the likelihood of negative consequences and the quantitative assessment of the contribution of production factors to the development of pathology [3].

The implementation of a risk-oriented classification of working conditions [4], which includes both the hygienic assessment of harmful factors and the analysis of medical-statistical data-such as morbidity rates and temporary loss of work capacity-acquires particular importance. The validity of the link between diseases and working conditions is confirmed by qualitative and quantitative methods [5].

Quantitative methods provide a numerical assessment of the level of risk and are especially in demand in high-risk industries.

For example, epidemiological methods such as cohort studies, case-control studies, and exposure assessment models [6] play a crucial role in studying the relationship between working conditions and morbidity. The main indicators are relative risk (RR) and etiological fraction (EF).

These indicators allow for a quantitative assessment of the likelihood of developing occupational diseases under certain conditions and the prediction of outcomes under various scenarios of the production environment.

The etiological fraction reflects the percentage of disease cases that can be directly attributed to occupational factors. Calculating the etiological fraction helps assess the potential effectiveness of preventive measures. For instance, if the etiological fraction is 60%, eliminating the exposure to the corresponding harmful factor could reduce morbidity by the same proportion [7].

In analytical epidemiological studies, where the main objective is to determine the etiology of diseases, it is important to assess the risk of disease development in groups exposed and not exposed to the suspected etiological factor. Therefore, the concept of relative risk has become widely used in epidemiological studies of the occupational environment. Relative risk is used to compare the frequency of diseases among workers exposed to occupational hazards with that in a control group. The value of relative risk indicates how many times greater the risk of developing a disease is when a person is exposed to a specific risk factor compared to when the factor is absent.

Relative risk shows the strength of the association between exposure to a harmful factor and disease (health impairment) and serves as a measure of the influence of occupational risk factors. It determines the likelihood of disease (health impairment) under the influence of the factor and the share of morbidity in the population attributed to the exposure to the risk factor.

For example, according to Schulte et al. [8], when RR>1.5, a significant relationship between exposure to occupational factors and disease frequency is observed, which justifies recognizing the risk as occupational.

Also noteworthy is the study [9], which presents a systematic review of the methodology for quantitative risk assessment, with particular emphasis on epidemiological tools for analyzing the impact of environmental and occupational factors on human health. A key focus of the discussion is the application of relative risk (RR) as one of the principal epidemiological indicators, enabling the estimation of the probability of adverse health outcomes (disease incidence) in exposed groups compared to control groups. The article examines the use of RR within the context of toxicological data, dose–response relationships, and uncertainties related to data sources.

Another study [10] emphasizes that relative risk (RR) is one of the fundamental indicators in epidemiological analysis, enabling the quantitative assessment of risk factor impacts on population health. RR is considered a critical tool for estimating the probability of disease development under the influence of specific risk exposures, particularly when comparing exposed and unexposed groups. The study highlights the importance of accurate calculation and interpretation of RR, taking into account confounding variables such as exposure levels, duration of exposure, and demographic characteristics. The findings underscore the relevance of RR in health risk assessment and the formulation of evidence-based preventive strategies.

The subsequent study [11] explores epidemiological approaches to the assessment of occupational risks among women employed in mining and petrochemical enterprises in the Republic of Bashkortostan, working under exposure to harmful industrial factors. The findings indicate that employees of the enrichment plant exhibit a very high degree of occupational attribution for musculoskeletal disorders (RR=4.3; EF=75%) and a high degree for respiratory diseases (RR=3.1; EF=67.7%). In the petrochemical sector, significantly elevated levels of chronic diseases were also identified among female workers compared to the control group, particularly affecting the nervous and cardiovascular systems. These results confirm the presence of high and moderate levels of occupational risk in these industrial sectors.

Another author Novikova et al. [12] conducted an occupational risk assessment in petroleum product manufacturing using relative risk (RR) and etiologic fraction (EF) indicators. Statistically significant associations were established between working conditions and the development of diseases, including musculoskeletal disorders (RR=1.77; EF=43%) and visual system impairments (RR=4.50; EF=78%). Various stages of the technological process exhibited risk levels ranging from moderate to high, with unacceptable values identified for dorsalgia and visual disturbances. These findings highlight the necessity of developing targeted preventive measures for different worker groups based on the nature of their occupational exposure.

A study by Sukhova and Preobrazhenskaya [13] investigated occupational hearing loss in workers of the mining industry exposed to combined noise and vibration. The authors reported that simultaneous exposure to noise and either local or whole-body vibration increased the risk of occupational hearing impairment by 1.82–1.85 times (RR=1.82–1.85), with an etiologic fraction (EF) of 45–46%, indicating a significant contribution of occupational exposure. Workers under such combined conditions showed signs of central auditory processing deficits, including impaired speech intelligibility. These findings emphasize the importance of implementing personalized hearing conservation programs based on the degree of occupational risk.

According to the findings presented in the study [14] for the Kuibyshev Oil Refinery, the highest levels of occupational risk were identified for ear diseases (hearing loss), with a relative risk (RR) of 16.7 and an etiologic fraction (EF) of 93.6%, indicating an almost complete degree of occupational attribution. Substantial risk indicators were also observed for respiratory diseases (RR=3.7; EF=72.7%), reflecting a very high level of occupational attribution, and for digestive system disorders (RR=1.7; EF=41.3%), corresponding to a moderate level of attribution. These results underscore the critical influence of working conditions on the development of chronic diseases among employees in the oil refining sector.

Thus, numerous studies have demonstrated the applicability of relative risk (RR) and etiologic fraction (EF) as key indicators for assessing the prevalence and attribution of occupational diseases across various industrial sectors.

The application of relative risk in the comprehensive assessment of working conditions enables not only the identification of high-risk worker groups but also the effective targeting of preventive measures to mitigate occupational hazards.

This study examines, using the example of a phosphorus plant, the causal relationship between working conditions and the development of occupational diseases, which serves as the basis for the development of a new classification of working conditions.

It is well known that phosphorus production is associated with exposure to a range of hazardous substances that can negatively affect workers' health [15].

The development of occupational diseases at phosphorus plants may be increased for the following reasons:

- Phosphorus dust and fumes can cause irritation of the skin and mucous membranes, as well as lead to respiratory diseases such as bronchitis and pneumoconiosis [16].
- Exposure to other chemicals. During the phosphorus production process, other substances such as sulfur dioxide, hydrogen fluoride, and ammonia [17] are used, which also have harmful effects on workers health.
- Physical factors. Working at a phosphorus plant is often associated with exposure to high temperatures [18] and noise [19], which can lead to heatstroke, hearing impairments, and other pathologies [20].

Modern working conditions at industrial enterprises, especially in the phosphorus plant, are characterized by exposure to numerous harmful factors that can have both acute and cumulative effects on workers health. Of particular concern is the rise of work-related diseases that are not included in the official list of occupational diseases but are closely related to the production environment.

In the context of transitioning to a risk-oriented occupational safety model in Kazakhstan, the importance of a scientifically grounded system for assessing professional risks is increasing, including the application of quantitative methods such as relative risk (RR) and etiological fraction (EF). Furthermore, the objective and reproducible link between a risk factor and disease becomes the foundation for developing new approaches to classifying working conditions.

Against the backdrop of rising morbidity among workers in hazardous industries (in particular, phosphorus plants), studying the causal relationships between working conditions and health status has gained significant practical and social importance. A justified classification of working conditions considering professional risks is necessary to create effective preventive strategies and adjust existing occupational safety regulations.

The scientific novelty of this study lies in the implementation of a comprehensive quantitative assessment of occupational risks at a phosphorus production facility using the indicators of relative risk (RR) and etiological fraction (EF), combined with a correlation analysis of the impact of harmful industrial factors. An original risk assessment matrix was developed and predictive models were constructed incorporating these metrics, enabling more accurate classification of hazard levels in industries with elevated occupational risk profiles. A significant distinction of this work is the adaptation of the applied methodology to the industrial context of Kazakhstan - this is the first application of such a quantitative risk assessment approach within the domestic chemical industry. Unlike most previous studies, which were limited to descriptive analyses of working conditions or general morbidity statistics, the present research applies evidence-based occupational medicine principles to establish causal relationships between specific occupational exposures (noise, various types of dust, chemical agents) and the development of occupational diseases among phosphorus plant workers. The uniqueness of the study also stems from its focus on an epidemiologically underexplored industry - yellow phosphorus production - which is characterized by highly toxic technological processes and a pronounced impact on workers' health. The findings of this research can serve as a foundation for prioritizing occupational risk management efforts, designing effective prevention strategies, and improving occupational safety systems at enterprises operating under similar conditions.

The aim of the study is to establish the causal relationship between working conditions and workers' health at a phosphate plant, as well as to scientifically substantiate a new risk-oriented classification of working conditions.

In this study, a quantitative assessment of professional risks was conducted using RR and EF indicators across five main workshops of the plant. Mathematical models were developed to illustrate the relationship between relative risk, the number of cases, and the etiological fraction, and a draft matrix of working conditions was created based on the new classification of harmful factors. The results allowed the identification of workshops with the highest professional correlation to health impairments and laid the foundation for a scientifically grounded system for occupational safety management.

2. METHODS AND MATERIALS OF RESEARCH

The object of the study is a phosphorus plant, one of the leading enterprises in the Republic of Kazakhstan, specializing in the production of yellow phosphorus and phosphorus-containing products.

Five workshops were selected for the study:

- Workshop No. 1 – unloading, reception, storage, crushing, and drying of raw materials.
- Workshop No. 2 – preparation of the charge from raw materials and sintering it into agglomerates in agglomeration machines AKM-7-312; crushing, cooling, and sorting of the resulting agglomerates; supplying the finished agglomerate to the yellow phosphorus workshop.
- Workshop No. 5 – preparation of the charge and production of yellow phosphorus by electrothermal distillation in RKZ-80 type furnace; draining and processing of ferrophosphorus and granulated slag.
- Workshop No. 7 – finishing yellow phosphorus to commercial quality by separating phosphorus sludge, washing rail tank cars, and filling them with commercial phosphorus for shipment to customers; burning of phosphorus sludge to produce phosphoric acid.
- Workshop No. 12 – supply of gaseous nitrogen, compressed air, control and instrumentation air, and gaseous

technical oxygen, produced by the low-temperature rectification of air, to the plant's workshops.

The study was conducted based on data from examinations of 1162 workers, including periodic medical check-ups, morbidity rates with temporary loss of work capacity (TLWC), and the hygienic assessment of working conditions in 5 workshops.

The degree of professional conditioning of health impairments was determined according to criteria adapted from the methodology developed by authors, taking into account the recommendations of the WHO and ILO [21].

According to this methodology, the degree of professional conditioning of health impairments, depending on relative risk, was determined using the table below (Table 1).

Table 1. Degree of professional conditioning of health impairments based on relative risk [21]

No.	Degree of Professional Conditioning	Relative Risk (RR)	Etiological Fraction (EF), %
(0)	Zero	0<RR≤1	0
1	Low	1<RR≤1.5	Less than 33
2	Moderate	1.5<RR≤2	33-50
3	High	2<RR≤3.2	51-66
4	Very high	3.2<RR≤5	67-80
5	Almost complete	RR>5	81-100

Relative risk (RR) was calculated using the following formula:

$$RR = \frac{a.f}{c.e} \quad (1)$$

where, a – number of cases in the experimental group;

c – number of cases in the control group;

e – total number of sick and healthy individuals in the experimental group;

f – total number of sick and healthy individuals in the control group.

The etiological fraction (EF) was determined using the following formula (2):

$$EF = \frac{(RR-1)}{RR}.100\% \quad (2)$$

To perform the assessment of relative risk (RR) and etiologic fraction (EF), two comparison groups were established:

Experimental group – comprised of employees from five production units of the phosphorus plant (Workshops №1, №2, №5, №7, and №12), directly engaged in activities involving exposure to harmful occupational factors. The total number of participants in the experimental group was 1,021 individuals.

Control group – consisted of employees not exposed to hazardous occupational factors, working under similar organizational and production conditions but without contact with the specific risk factors under study. The total number of participants in the control group was 141 individuals.

Health status assessments were conducted for both groups, followed by the calculation of RR and EF values across major disease categories, including injuries, upper respiratory tract diseases, sensory disorders, cardiovascular diseases, musculoskeletal disorders, genitourinary conditions, and gastrointestinal diseases. The calculations were performed based on formulas (1 and 2), taking into account the incidence rates within each group.

All recorded diseases were classified according to the ICD-10 classification system.

To identify the relationship between influencing factors and morbidity rates among workers at the phosphate plant, a correlation analysis was conducted using Pearson's correlation coefficient. This method allows for the quantitative assessment of the degree of linear dependence between two variables.

Two-tailed significance (p-value) was used to assess the statistical significance of the identified correlations. A value of $p<0.05$ indicated a significant correlation, while $p<0.01$ indicated a highly significant correlation.

Statistical processing of the results was performed using the STATISTICA 10.0 software package.

To determine the degree of association between workers' health impairments in key professions, a hygienic assessment and classification of working conditions were conducted [22].

3. RESULTS AND DISCUSSION

Based on formulas (1) and (2) calculations of relative risk (RR) and etiological fraction (EF) were performed for each disease category and each production workshop. The resulting values reflect the degree of occupational attribution of the identified diseases and enable classification of risk levels across different workshops.

The calculation results are summarized in Tables 2-6, providing clarity for the analysis and reproducibility of the applied methodology.

Table 2. RR and EF values for major disease types in workshop No.1

Groups	Total	Sick	Injuries	Upper Respiratory Tract Diseases	Sensory Disorders	Cardiovascular System	Gastrointestinal Diseases	Urinary System Diseases	Musculoskeletal Diseases	Allergic Disease	Other Diseases
Control	22	18	2	5	0	1	2	1	1	2	4
Experimental	129	75	11	43	1	0	10	0	10	0	0
RR			0.9	1.47	0	0	0.9	0	1.7	0	0
EF, %			-6.60	31.97	0	0	-11.00	0	41.2	0	0
Degree of conditioning			zero	low			zero		moderate		

Table 3. RR and EF values for major disease types in workshop No.2

Groups	Total	Sick	Injuries	Upper Respiratory Tract Diseases	Sensory Disorders	Cardiovascular System	Gastrointestinal Diseases	Urinary System Diseases	Musculoskeletal Diseases	Allergic Disease	Skin and Vein Disease
Control	31	13	2	8	1	1	0	0	1	0	0
Experimental	325	146	14	77	2	5	7	1	35	1	1
RR			0.68	0.92	0.19	0.5	0	0	3.34	0	0
EF, %			-49.80	-7.60	-426.32	-107.30	0	0	67.85	0	0
Degree of conditioning			zero	zero	zero	zero			very high		

Table 4. RR and EF values for major disease types in workshop No.5

Groups	Total	Sick	Injuries	Upper Respiratory Tract Diseases	Sensory Disorders	Cardiovascular System	Gastrointestinal Diseases	Urinary System Diseases	Musculoskeletal Diseases	Allergic Diseases	Other Diseases
Control	49	10	1	4	0	1	1	0	2	1	0
Experimental	405	205	21	108	1	11	11	4	33	4	12
RR			2.5	3.27	0	1.33	1.33	0	2.00	0.5	0
EF, %			60.64	69.39	0	23.10	23.10	0	49.91	-100,00	0
Degree of conditioning			high	very high		low	low		moderate	zero	

Table 5. RR and EF values for major disease types in workshop No.7

Groups	Total	Sick	Injuries	Upper Respiratory Tract Diseases	Sensory Disorders	Cardiovascular System	Gastrointestinal Diseases	Urinary System Diseases	Musculoskeletal Diseases
Control	28	14	1	5	1	1	0	0	6
Experimental	117	93	6	62	1	5	11	2	6
RR			1.44	6.57	0.24	1.20	0	0	1.44
EF, %			30.36	84.80	-316.67	16.40	0	0	30.40
Degree of conditioning			low	almost complete	zero	low			low

Table 6. RR and EF values for major disease types in workshop No.12

Groups	Total	Sick	Injuries	Upper Respiratory Tract Diseases	Sensory Disorders	Cardiovascular System	Gastrointestinal Diseases	Urinary System Diseases	Musculoskeletal Diseases
Control	11	2	0	1	0	1	0	0	0
Experimental	45	35	1	14	14	3	1	1	3
RR			0	3.42	3.42	0	0	0	0
EF, %			0	70.80	70.80				0
Degree of conditioning				very high	very high				

The analysis of the calculated RR and EF indicators revealed substantial variability in the level of occupational risks across the workshops of the phosphorus plant. According to the results, 57 cases of disease were recorded in the control group (141 individuals) not exposed to harmful occupational factors. In contrast, the experimental group, comprising 1,021 workers employed under hazardous working conditions, reported 554 cases of disease. These findings indicate a significant disparity in morbidity rates between the groups and confirm the presence of occupationally attributable risk.

Based on the preliminary data, graphs were created showing the relationship between relative risk and the number of cases in the experimental group, as well as the etiological fraction in each workshop of the plant.

Below, Figures 1-5 present the corresponding relationships for the five main workshops, reflecting differences in the structure and severity of occupational diseases.

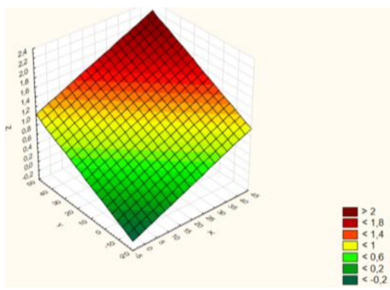

Figure 1. Graph of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction (Workshop No. 1)

Note: Variable 1 (x) – Number of cases in the experimental group, variable 2 (y) – EF (etiological fraction), variable 3 (z) – RR (relative risk)

To predict working conditions in the presence of work-related diseases, the following relationship between relative risk, the number of cases in the experimental group, and the etiological fraction for Workshop No. 1 was established, which is expressed by the following Eq. (3):

$$z = 0.2662+0.0232\cdot x+0.0176\cdot y \quad (3)$$

Figure 2 shows the graph of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction for workers in Workshop No. 2.

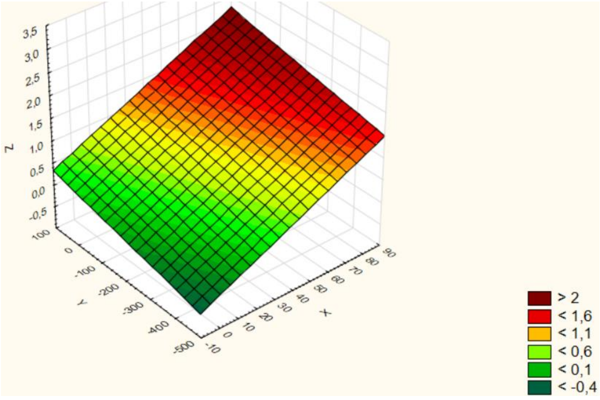

Figure 2. Graph of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction (Workshop No. 2)

The model of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction for Workshop No. 2 (agglomerate production) is expressed by the following Eq. (4):

$$z = 0.3932 + 0.0194\cdot x + 0.0013\cdot y \quad (4)$$

In the next Figure 3, the graph of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction for workers in Workshop No. 5 is presented.

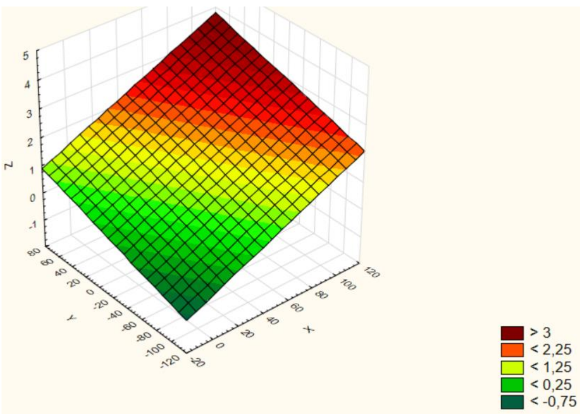

Figure 3. Graph of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction (Workshop No. 5)

The model of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction for Workshop No. 5 is expressed by the following Eq. (5):

$$z = 0.6151 + 0.021\cdot x + 0.0087\cdot y \quad (5)$$

In the next Figure 4, the graph of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction for workers in Workshop No. 7 is presented.

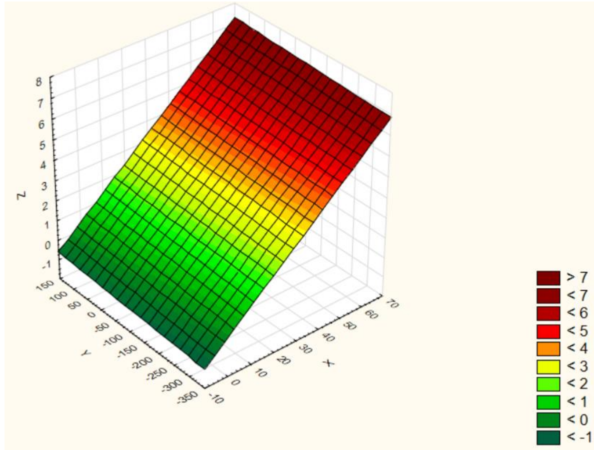

Figure 4. Graph of the relationship between RR, the number of cases in the experimental group, and the EF (Workshop No. 7)

The model of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction for Workshop No. 7 is expressed by the following Eq. (6):

$$z = 0.2634 + 0.0987\cdot x + 0.0009\cdot y \quad (6)$$

In Figure 5, the graph of the relationship between relative risk, the number of cases in the experimental group, and the EF for workers in Workshop No. 12 is presented.

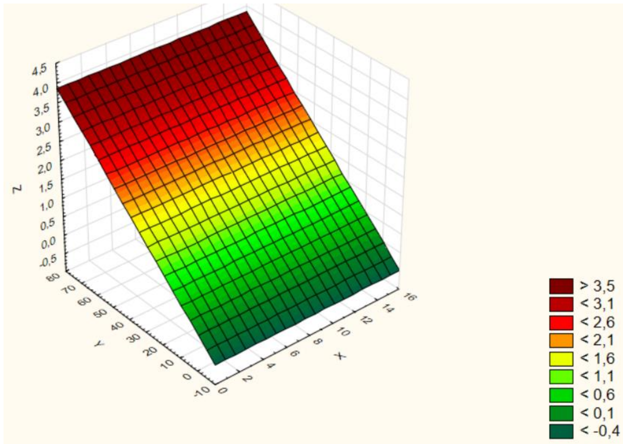

Figure 5. Graph of the relationship between RR, the number of cases in the experimental group, and the EF (Workshop No. 12)

The model of the relationship between relative risk, the number of cases in the experimental group, and the etiological fraction for Workshop No. 12 is expressed by the following Eq. (7):

$$z = 4.5519E\text{-}15 - 2.6275E\text{-}15\cdot x + 0.0483\cdot y \quad (7)$$

Analysis of the graphs showing the relationship between relative risk (RR), the number of cases in the experimental group (x), and the etiological fraction (EF, y) for the five workshops (Figures 1-5) revealed a pronounced linear relationship between the variables, reflecting the increase in occupational risks with the rising morbidity and the contribution of production factors to the structure of diseases.

The mathematical models obtained from the regression analysis describe the degree of influence of the number of cases (x) and the etiological fraction (y) on the value of relative risk (z).

The most pronounced influence is observed in Workshop No. 7 and No. 5, where the coefficients for x and y in the equations were higher compared to the other workshops, indicating a high sensitivity of the risk level to changes in the number of cases and the etiological fraction. In Workshop No. 1, the model showed a moderate dependence of RR on x and y, which corresponds to the relatively low values of RR and EF recorded in the tables. In Workshop No. 2, the coefficient for y is significantly lower, indicating a weak influence of EF on RR and, consequently, a less pronounced professional conditioning of diseases. In Workshop No. 5, the values of the coefficients for x and y increase, reflecting a consistent trend of increasing RR as the number of cases and EF rise. In Workshop No. 7, the highest value of the coefficient for x is observed, indicating a significant dependence of RR on the number of cases, as well as a high professional conditioning of diseases. In Workshop No. 12, the model takes a less typical form, with an almost zero contribution from x and a dominant influence from y, which suggests the extremely high role of the etiological fraction in forming RR, while the number of cases has almost no effect on the final risk.

Thus, the models show that in different workshops, the level of occupational risk is determined by different ratios of EF contribution and the number of cases. The contribution of EF is particularly significant in Workshops No. 5 and No. 12, while the number of cases has a stronger influence on RR in Workshop No. 7. The obtained relationships allow the developed models to be used for forecasting occupational risks and planning preventive measures in production.

For a comprehensive assessment of occupational risk and the degree of influence of working conditions on workers' health, a summary interpretation of the data (Tables 2-6) for each production workshop was carried out based on the calculations of relative risk (RR), etiological fraction (EF), and classification of the degree of professional conditioning of diseases. The results are summarized in Table 7, reflecting the integral assessment of the damage to the professional health of workers in key professions (WKP) for each division of the enterprise.

The obtained data demonstrate significant differences in the levels of occupational risk between workshops. Based on the analysis conducted (Table 7) for the enterprise, two workshops (No. 12 and No. 5) with high and very high levels of relative risk were identified, which stand out as some of the most hazardous to workers' health.

Table 7. Assessment of the degree of association between health impairments of workers in key professions (WKP) and working in production workshops

Group of Workers	Assessment of Professional Health Damage (Resulting Factor)			
	Relative Risk (RR)	Etiological Fraction (EF, %)	Degree of Professional Conditioning	Probabilistic Assessment of the Nature of Health Impairments
WKP Workshop No. 1	0.7	-42.9	Zero	General diseases
WKP Workshop No. 2	1.1	9.1	Low	General diseases
WKP Workshop No. 7	1.6	37.5	Moderate	Work-related diseases
WKP Workshop No. 5	2.5	60.0	High	Work-related diseases
WKP Workshop No. 5	4.3	76.7	Very high	Work-related diseases

In Workshop No. 12, a very high level of occupational risk was recorded (RR=4.3, EF=76.7%), indicating a strong relationship between working conditions and the development of sensory system diseases. The highest level of occupational risk is attributed to continuous exposure to elevated concentrations of phosphorus aerosols, as well as substantial exceedances of the maximum allowable concentration (MAC) for phosphorite dust and noise (average level of 93 dB). This production area is also characterized by a high density of technological equipment and the presence of Class II hazardous chemical substances. The degree of professional conditioning of diseases in this division is rated as very high (67–80%), requiring immediate preventive measures.

In Workshop No.5, a proven occupational risk was established (RR=2.5, EF=60%), indicating a significant impact of working conditions on workers' health. Respiratory system diseases (bronchitis, tonsillitis, pharyngitis, sinusitis, angina, asthma, ARVI, and ARD) constitute the main structure of morbidity, and the degree of professional conditioning of diseases is rated as high (51–66%). A significant level of occupational risk is associated with exposure to dust generated during the roasting of coke-phosphate mixtures, accompanied by simultaneous exposure to vibration, heat stress, and intense physical exertion.

In Workshop No. 7, the values of relative risk (RR) and etiological fraction (EF) correspond to a moderate level. This workshop is characterized by high physical workload, prolonged standing, manual lifting, and moderate exposure to noise and vibration, which correlates with an increased incidence of musculoskeletal disorders.

In contrast, Workshops No. 1 and No. 2 exhibit low or zero RR and EF values across most disease categories, indicating minimal occupational impact. These production units are distinguished by more favorable sanitary and hygienic conditions. The noise levels do not exceed 75 dB, and the airborne dust does not contain toxic components.

For the purpose of comparative analysis, a relevant study conducted in the chemical industry - specifically at facilities processing sylvinite for the production of potassium fertilizers [23] was selected. This study also utilized RR and EF indicators to assess the risk of respiratory diseases. According to the published data, RR values were 1.52 (EF=34.2%) in the mining division, 1.72 (EF=41.9%) at Sylvinite Processing Plant No. 1 (SPP-1), and 2.16 (EF=53.7%) at at Sylvinite Processing Plant No. 2 (SPP-2).

The values obtained in the present study for Workshop No. 5 (RR=2.5, EF=60.0%) are comparable to those observed at SPP-2, confirming a high degree of occupational attribution for respiratory disorders. Meanwhile, the values reported for Workshop No. 12 (RR=4.3, EF=76.7%) significantly exceed those presented in the Bahdanovich study [23], indicating extremely unfavorable working conditions in this unit and a uniquely high level of occupational risk. These findings emphasize not only the applicability of RR and EF indicators in industrial epidemiology but also highlight regional specificities of occupational hazards within the chemical sector.

The study also included an in-depth correlation analysis aimed at quantitatively assessing occupational risks by identifying statistically significant causal relationships between the levels of exposure to harmful production factors and the indicators of work-related diseases. This allowed for the justification of the leading determinants of occupational risk in the context of the phosphorus plant.

The results of the correlation calculation between morbidity indicators and influencing factors in Workshop No. 5 showed a strong positive dependence between the level of inorganic dust (quartzite) and the frequency of upper respiratory diseases ($r=0.97$, $p<0.01$). A strong positive correlation was also established between the level of dust from inorganic materials (coke, phosphate, gypsum) and the frequency of upper respiratory diseases ($r=0.84$, $p<0.01$). A moderate positive correlation was found between the level of phosphine dust and the frequency of upper respiratory diseases ($r=0.34$, $p<0.01$). Additionally, a moderate positive correlation was found between the level of phosphine dust and the frequency of gastrointestinal diseases ($r=0.38$, $p<0.01$).

The interpretation of the results of the impact of different types of inorganic dust on the frequency of upper respiratory diseases is presented in Figures 6 and 7.

The coefficient of determination ($R^2=0.7809$) indicates a moderate positive correlation between the number of diseases and the level of inorganic dust.

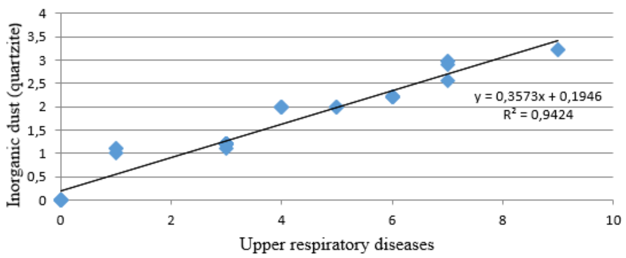

Figure 6. The impact of inorganic dust (quartzite) on the frequency of upper respiratory diseases (Workshop No. 5)

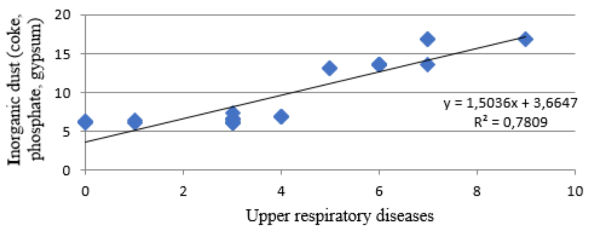

Figure 7. The impact of inorganic dust (coke, phosphate, gypsum) on the frequency of upper respiratory diseases (Workshop No. 5)

The calculated correlation between morbidity indicators and influencing factors in Workshop No. 12 demonstrated a moderate positive correlation between the level of nitrogen dioxide and the frequency of upper respiratory diseases ($r=0.40$, $p<0.05$).

A moderate positive correlation was also found between the level of industrial noise and the frequency of sensory diseases ($r=0.40$, $p<0.05$), which may indicate the impact of noise on sensory functions of the body.

The interpretation of the results of the impact of nitrogen dioxide on the frequency of upper respiratory diseases is presented in Figure 8.

The coefficient of determination ($R^2=0.9415$) represents a very high value, indicating a strong positive correlation between the number of diseases and the level of nitrogen dioxide. This means that approximately 94.15% of the variation in NO_2 concentration is explained by changes in the number of diseases.

The identified statistically significant correlation relationships between the exposure levels of the mentioned factors and the morbidity indicators confirm their determining role in the formation of occupational risks.

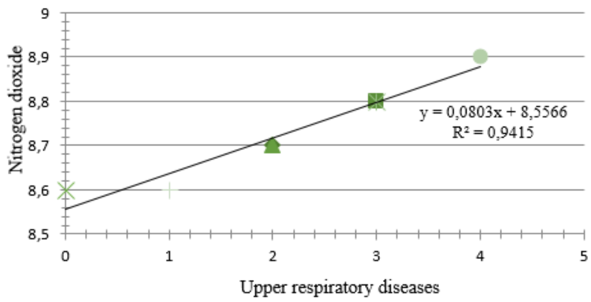

Figure 8. The impact of nitrogen dioxide on the frequency of upper respiratory diseases (Workshop No. 12)

Based on the obtained results, a matrix for assessing working conditions according to harmful production factors (Table 8) has been developed, based on the proposed new classification, which allows for the quantitative assessment of risks and the development of preventive measures.

In the draft matrix for assessing working conditions based on harmful production factors, 3 criteria for evaluating working conditions have been developed based on the following indicators: health status based on the results of periodic medical examinations [24], morbidity with temporary loss of work capacity [25]; indicators of mortality, premature death, disability, and loss of professional fitness [26].

The implementation of such a classification will significantly expand the possibilities for risk monitoring, as it takes into account the damage to workers' health as a resulting effect of harmful factors, which is a delayed result of the negative impact of the production environment and the production process.

This matrix allows for the classification of working conditions based on the significance of the impact of harmful production factors, as well as the establishment of causal relationships between their impact on workers' health at the early stages of pathology.

Table 8. Matrix for assessing working conditions based on harmful production factors

Class of Working Conditions According to Harmful Production Factors (New Classification)	Harmful and Hazardous Factors of the Production Environment and the Severity of the Labor Process [22]	General Hygienic Assessment (Presumed Occupational Risk)	Assessment of Professional Health Damage (Resulting Factor)				
			Health Condition Indicators Based on the Results of Periodic Medical Examinations [24]	Morbidity Indicators with Temporary Loss of Work Capacity (TLWC) for One Disease over the Last 12 Months [25]	Indicators of Mortality, Premature Death, Disability, Loss of Professional Fitness [26]	Relative Risk (RR)	Etiological Fraction (EF), %
Acceptable working conditions (1)	Severity and intensity of the labor process	Optimal working conditions (Class 1); Acceptable working conditions (Class 2)	Practically healthy worker, professionally fit, or temporarily unfit for work, requiring outpatient or inpatient further examination and treatment	Sick leave for one disease not exceeding twenty calendar days	-	0<RR≤1 Suspected occupational risk	0 Degree of association is absent (zero)
Harmful working conditions of moderate severity (2.1)	Insufficient lighting; Vibration; Severity and intensity of the labor process	1st degree of Class 3 (subclass 3.1)	The worker is temporarily unfit for work, requires inpatient further examination and treatment, needs outpatient monitoring, and sanatorium-resort treatment	Sick leave for more than 20 days, up to 60 days	Transfer to light work for a period of 2 to 6 months	1<RR≤1.5 Suspected occupational risk	Less than 33 Degree of association is low
Harmful working conditions of significant severity (2.2)	Inorganic dust (coke, phosphate, gypsum, quartzite, agglomerate, charge, phosphine, white phosphorus, nitrogen dioxide, calcined soda); Severity and intensity of the labor process	2nd degree of Class 3 (subclass 3.2)	There is suspicion of work-related and/or occupational diseases, requiring examination at a professional pathology center	Long-term sick, working individuals with sick leave: 1. 1.No earlier than 4 months or no later than five months within the last 12 months 2.No earlier than four months from the onset of temporary disability due to injuries, if there is a prospective prognosis of the disease course, based on the decision of the Medical Advisory Commission (MAC), the sick leave is extended for two months	DLPWC (degree of loss of professional work capacity) from 5 to 29% [18]	1.5<RR≤2 Suspected occupational risk	33-50 Degree of association is moderate
Harmful working conditions of high severity (2.3)	Severity and intensity of the labor process	3rd degree of Class 3 (subclass 3.3)	There is suspicion of work-related and/or occupational diseases, requiring examination at a professional pathology center	Long-term sick: 1. No earlier than four months or no later than five months of temporary disability within the last twelve months in case of recurrent illnesses	DLPWC from 30 to 59%"	2<RR≤3.2 Proven occupational risk	51-66 Degree of association is high

Harmful working conditions of very high severity (2.4)	Industrial noise; Severity and intensity of the labor process	4th degree of Class 3 (subclass 3.4)	There is suspicion of work-related and/or occupational diseases, requiring examination at a professional pathology center	Working individuals with disabilities are referred to the Medical and Social Expert Commission (MSEC) if their health deteriorates no earlier than two months from the onset of temporary disability	DLPWC from 60 to 89%	$3.2<RR\leq 5$ Proven occupational risk	67-80 Degree of association is very high
		Hazardous (extreme) working conditions (Class 4)		Death due to an occupational disease	DLPWC from 90 to 100 %	$RR>5$ Proven occupational risk	81-100 Degree of association is almost complete

1. Acceptable working conditions correspond to Class 1 and Class 2 of the general hygienic assessment of optimal and acceptable working conditions [22]. The assessment of professional health damage in this case is not related to professional activity and is characterized by the following parameters:

- Practically healthy worker, professionally fit, or temporarily unfit for work, requiring outpatient or inpatient further examination and treatment;
- Sick leave for one disease not exceeding 20 calendar days;
- Suspected occupational (relative) risk ($0< RR\leq 1$);

2. Harmful working conditions correspond to Class 3 and Class 4 of the general hygienic assessment of working conditions and are subdivided into 4 degrees: moderate, significant, high, and very high severity.

2.1. Harmful working conditions of moderate severity correspond to subclass 3.1 of the general hygienic assessment of working conditions and/or have a low (less than 33%) etiological connection between professional activity and health damage, but occupational risk is not excluded and is assessed as suspected ($1<RR\leq 1.5$):

- The worker is temporarily unfit for work, requires inpatient further examination and treatment, needs outpatient monitoring, and sanatorium-resort treatment;
- Sick leave for one disease is issued for a period of more than 20 days but not exceeding 60 calendar days, except for pregnancy and childbirth, as well as diseases listed in the List of Diseases for which the period of temporary disability is more than two months, according to paragraph 2 of Article 89 of the Labor Code of the Republic of Kazakhstan [27];
- If, according to the conclusion of the Medical Consultative Commission (MCC), there is no reason for referral for medical and social expertise (MSE) to establish disability, but working conditions worsen the clinical course and prognosis of the disease, the MCC issues a conclusion for temporary transfer to lighter work for a period of two to six months, with the period set by the MCC depending on the profession (specialization), severity of the disease course, and complications.

2.2. Harmful working conditions of significant severity correspond to subclass 3.2 of the general hygienic assessment of working conditions and/or have a moderate etiological connection with professional activity (from 33 to 50%). The occupational risk shifts from suspected to presumed ($1.5<RR\leq 2$) and requires inclusion in the company's strategy for further management of its "green" portfolio in the context of "green" jobs. The analysis of significance in this context implies an internal assessment of the impact of harmful production factors on workers' health, their dynamic monitoring and control, the development of preventive measures, and inclusion in non-financial reporting as a key performance indicator.

Harmful working conditions of significant severity are characterized by the following parameters, obtained from annual medical examinations and analysis of workers' morbidity:

- There is suspicion of an occupational and/or work-related disease, requiring examination at a professional pathology center;
- Long-term sick, working individuals with sick leave:

1. No earlier than four months from the onset of temporary disability or no later than five months of temporary disability within the last twelve months for recurrent illnesses (for the same disease);
2. No earlier than four months from the onset of temporary disability due to injuries, if there is a prospective prognosis for the disease course, based on the decision of the Medical Consultative Commission (MCC), sick leave is extended for two months;

- Referred to the Medical and Social Expert Commission (MSE), with a degree of loss of professional work capacity from 5 to 29% - the worker is not contraindicated for professional activity with moderate or minor reduction in qualification, or with a decrease in the volume of work performed, or if performing their professional activity requires more effort than before, and/or in cases of occupational diseases with reduced exposure to harmful and/or hazardous production factors due to minimally expressed impairment of body functions.

2.3. Harmful working conditions of high severity correspond to subclass 3.3 of the general hygienic assessment of working conditions and/or have a high etiological connection with morbidity (51% to 66%) and proven occupational risk ($2<RR\leq 3.2$);

- There is suspicion of work-related and/or occupational diseases, requiring examination at a professional pathology center;

- Long-term sick, working individuals with sick leave:

1. No earlier than four months from the onset of temporary disability or no later than five months of temporary disability within the last twelve months for recurrent illnesses (for the same disease);

2. No earlier than four months from the onset of temporary disability due to injuries, if there is a prospective prognosis for the disease course, based on the decision of the Medical Consultative Commission (MCC), sick leave is extended for two months;

- Referred to the Medical and Social Expert Commission (MSE), with a degree of loss of professional work capacity (SUTP) from 30 to 59%, the worker is not contraindicated for professional activity under normal production conditions with significant reduction in qualification, or has lost the ability to continue professional activity and/or in cases of occupational diseases without exposure to harmful and/or hazardous production factors, due to moderately expressed impairment of body functions.

2.4. Harmful working conditions of very high severity correspond to subclass 3.4 and hazardous (extreme) working conditions of the general hygienic assessment of working conditions and/or have a very high etiological connection with morbidity (from 67% to 100%) and proven occupational risk ($3.2<RR\leq 5$ or $RR>5$);

- There is suspicion of work-related and/or occupational diseases, requiring examination at a professional pathology center;

- Working individuals with disabilities are referred to the Medical and Social Expert Commission (MSE) if their health deteriorates due to an incapacitating occupational disease no earlier than two months from the onset of temporary disability;

- The MSE has established disability due to an occupational disease with a degree of loss of professional work capacity (DLPWC) from 60 to 89%, professional activity is only possible under specially created conditions, where the disabled worker is given reduced working hours, and a special workplace is created equipped according to the individual's capabilities in accordance with the legislation of the Republic of Kazakhstan;

- Or, with DLPWC from 90 to 100%, there are pronounced functional impairments, with absolute contraindications for performing any type of activity, even in specially created conditions;

- Death due to an occupational disease.

Thus, the matrix for assessing working conditions is an effective tool for comprehensive assessment and management of occupational risks, providing the ability to identify health threats to workers and develop preventive measures to minimize and prevent them.

The obtained data can serve as a scientific basis for building predictive models for risk assessment and developing effective preventive and management strategies aimed at minimizing the impact of harmful production factors and improving working conditions at industrial enterprises.

4. CONCLUSIONS

The comprehensive analysis of working conditions and workers' health in five production divisions of the pilot enterprise revealed varying degrees of impact of working conditions on the development of diseases.

To assess the specifics of professional risks and the level of disease association with working conditions in different divisions of the enterprise, the interpretation of the RR and EF indicators was provided for each of the analyzed workshops.

A high level of risk was recorded in Workshop No. 12 (RR=4.3, EF=76.7%) and Workshop No. 5 (RR=2.5, EF=60.0%), which is associated with the impact of chemical factors and elevated noise levels.

A moderate level of risk was noted in Workshop No. 7 (RR=1.6, EF=37.5%), where musculoskeletal diseases predominate.

A low level of risk was identified in Workshop No. 2 (RR=1.1, EF=9.1%) and Workshop No. 1 (RR=0.7, EF=-42.9%), indicating no established link between working conditions and diseases.

The developed mathematical models of the relationship between RR, EF, and the number of cases showed that, in most divisions, the contribution of EF to the increased risk is higher than the impact of the number of cases. This is particularly evident in Workshop No. 12, where the coefficient for y=0.0483.

For a deeper understanding of the relationship between working conditions and occupational diseases, a correlation analysis was conducted between morbidity indicators and influencing factors (noise, inorganic dust, chemicals). The results of the correlation analysis identified key harmful production factors statistically associated with the development of occupational diseases of the respiratory, sensory systems, and gastrointestinal organs in workers at the phosphate production facility. It was found that the most pronounced negative impact is caused by inorganic aerosols, nitrogen dioxide, and phosphine.

Based on the results, a matrix model for assessing working conditions was developed, including key harmful factors such as inorganic dust, noise, vibration, insufficient lighting, and the severity and intensity of the labor process. The model is adapted to the new classification of working conditions in the Republic of Kazakhstan and allows for the classification of workplaces into the corresponding classes and subclasses of working conditions. The proposed matrix for classifying working conditions can also be used at similar phosphate plants abroad.

The obtained data emphasize the need for regular monitoring of professional health, integration of hygienic and medical-statistical approaches, and a review of organizational occupational safety measures. The application of a risk-oriented approach allows for the identification of high-risk areas and timely response to the deterioration of workers' health, preventing the development of occupational diseases and loss of work capacity.

Thus, the results of the study can serve as a basis for the implementation of integrated professional health systems in countries with developing industries and can be used in international research on harmonizing occupational safety and health standards for workers.

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