



Dynamic Occupational Risk Assessment as a Basis for Proactive Safety Management in Construction

Lyazat Aktayeva¹, Alimzhan Bekmagambetov¹, Anar Rakhmetova^{1*}, Gulzhan Daumova²,
Laura Yedilbayeva¹, Elmira Kulmagambetova¹, Gulnaziya Alshynbekova¹, Aizada Yerkinbekova¹

¹ Republican Research Institute for Occupational Safety and Health, Astana 010000, Kazakhstan

² School of Earth Sciences, D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk 070018, Kazakhstan

Corresponding Author Email: rakhmetovaanar68@gmail.com

Copyright: ©2026 The authors. This article is published by IETA and is licensed under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

<https://doi.org/10.18280/ijssse.160814>

ABSTRACT

Received: 18 June 2026

Revised: 11 August 2026

Accepted: 21 August 2026

Available online: 31 August 2026

Keywords:

occupational safety, construction industry, proactive safety management, construction sites, occupational health and safety, risk-based approach

Construction remains one of the most hazardous industrial sectors due to the combined effects of technical, organizational, environmental, and climatic risk factors. This study aimed to develop and test a dynamic approach to occupational risk assessment in the construction industry, taking into account hazardous occupational factors and extreme climatic conditions, and to analyze associations between occupational environmental indicators and recorded morbidity among workers. The methodology combined occupational hygiene assessment, analysis of recorded morbidity, and correlation, regression, and epidemiological risk analyses. Dynamic occupational risk assessment (DORA) tools, including safety checklists for work at height and outdoor work, were developed and tested to support timely hazard identification under changing working conditions. The results revealed distinct occupational risk profiles at the two pilot enterprises. At Enterprise 1, the most pronounced associations were related to physical workload and microclimatic conditions, including associations of work intensity and air temperature with upper respiratory tract diseases ($r = 0.816$ and $r = 0.818$, respectively; $p < 0.001$). At Enterprise 2, chemical aerosols and dust were predominant, with the strongest association observed between quartz-containing inorganic dust and respiratory diseases ($r = 0.970$; $p < 0.001$). The findings support differentiated occupational risk management according to site-specific technological, exposure, and climatic conditions. Integration of occupational exposure monitoring with dynamic risk assessment may provide a practical basis for proactive occupational safety management in construction.

1. INTRODUCTION

The construction industry remains one of the most hazardous economic sectors due to the combined influence of technical, organizational, and environmental risk factors. Construction workers are exposed to a wide range of occupational hazards that contribute to a high incidence of injuries and work-related diseases. Therefore, ensuring the safety of both construction facilities and construction personnel remains a strategic priority. This is driven by compliance with international occupational health and safety (OHS) standards, corporate social responsibility principles, and the economic consequences of occupational accidents for construction companies. Despite the implementation of advanced OHS standards and modern safety technologies, accident and injury rates in the construction sector remain high because of physically demanding work, interaction with heavy machinery, and exposure to adverse environmental conditions [1].

International studies have demonstrated that comprehensive safety management approaches, including occupational health and safety management systems (OHSMS) and digital technologies such as Building Information Modeling (BIM),

Virtual Reality (VR), Augmented Reality (AR), and the Internet of Things (IoT), can substantially reduce occupational injuries and improve workplace safety [2-7]. However, the implementation of these approaches remains limited in developing countries, including the Republic of Kazakhstan, reducing the effectiveness of accident prevention and highlighting the need to adapt international best practices to national conditions.

A review of the scientific literature indicates that construction site safety is determined by the complex interaction of technical, organizational, and human factors. Most occupational accidents result from combinations of multiple risk factors, including poor work organization, inadequate safety management systems, and insufficient worker competence [2, 5]. Although numerous studies have investigated construction safety management, limited attention has been paid to the integrated application of OHSMS together with digital technologies for improving worker safety in Central Asia and the Republic of Kazakhstan. This research gap determines the scientific novelty and practical significance of the present study.

Recent studies have emphasized the effectiveness of certified OHSMS compliant with ISO 45001 and previously

OHSAS 18001. The study [3] reported that implementation of OHSMS reduced overall occupational injuries by 67% and occupational fatalities by 10.3%. Furthermore, immersive and digital technologies, including VR, AR, and BIM, enable the simulation of safe work processes, prediction of hazardous situations, and rapid response to emerging risks [4, 5].

The principal causes of occupational injuries on construction sites include falls from height, electric shock, improper equipment operation, exposure to dust and noise, as well as organizational and behavioral risk factors [8]. These hazards are often interrelated. Inadequate worker training and motivation, insufficient supervision, and poor coordination among contractors and subcontractors considerably increase the likelihood of occupational accidents. Previous environmental and occupational safety studies have also demonstrated that exposure to hazardous agents such as dust, noise, and chemical contaminants significantly affects workers' health, increases the risk of occupational diseases, and reduces overall workplace safety [9].

International evidence indicates that effective safety management requires systematic hazard identification, risk assessment using proactive safety indicators, implementation of OHSMS, and application of digital technologies such as BIM, VR, and AR for worker training and real-time safety monitoring [3-8]. Recent advances in BIM, digital twins, wearable sensors, and real-time monitoring technologies have demonstrated considerable potential for proactive occupational risk management on construction sites.

Current research identifies several categories of occupational hazards that have the greatest impact on construction worker safety [10, 11]. Falls from height remain one of the leading causes of severe injuries and fatalities worldwide, accounting for approximately 30-40% of fatal construction accidents [1, 2]. Inadequate use of guardrails, fall-arrest systems, and collective protective equipment substantially increases accident risk. Systematic risk categorization and assessment facilitate the development of targeted preventive measures [12]. Mechanical hazards also include falling objects and unstable structures. Hazard identification methods and structured safety checklists improve the detection of critical risk areas and support preventive interventions aimed at reducing occupational injuries [13].

Improper operation of machinery and equipment is another major contributor to occupational accidents. Failure to comply with operating procedures, incorrect equipment setup, and insufficient supervision significantly increase the probability of mechanical injuries [3]. Electrical hazards are likewise associated with violations of safety regulations, inadequate equipment maintenance, and insufficient worker qualifications.

Beyond physical and technical hazards, organizational and behavioral factors-including inadequate safety culture, insufficient worker training, poor communication among contractors, and excessive reliance on lagging rather than leading safety indicators-have been recognized as critical determinants of construction safety performance [5, 10]. These factors frequently amplify the effects of technical hazards and contribute to complex accident scenarios.

Recent studies increasingly focus on systematic accident analysis and the development of preventive methodologies. Contemporary research demonstrates that effective construction safety management requires integrating organizational, technological, and behavioral factors while

applying advanced risk assessment techniques and predictive analytics [14-16]. Systematic reviews consistently identify insufficient worker training, deficiencies in construction management, poor compliance with safety regulations, human error, and organizational shortcomings as the principal causes of occupational accidents [12, 16].

Another important research direction concerns quantitative occupational risk assessment methods. Modern risk assessment techniques enable identification of high-risk construction activities and support the development of effective preventive measures for reducing occupational injuries [15]. In addition, predictive models based on big data analytics and machine learning have shown considerable potential for identifying hidden accident patterns and forecasting hazardous situations on construction sites [7, 16-18].

Overall, the available evidence indicates that contemporary construction safety research is focused on developing integrated risk management strategies combining OHSMS, digital technologies, safety culture development, and intelligent data analysis. The combined application of these approaches can substantially improve worker safety and reduce occupational accidents [19]. Nevertheless, the identified risk factors require adaptive assessment and management methods that consider the specific construction conditions of the Republic of Kazakhstan. Previous studies have also highlighted the importance of classifying workers according to occupational risk and health status, thereby providing the foundation for medical and functional assessment within the context of the transition toward a green economy [20].

The aim of this study was to develop and test a dynamic approach to occupational risk assessment in the construction industry, taking into account hazardous occupational factors and extreme climatic conditions, and to analyze associations between occupational environmental indicators and recorded morbidity among workers. The study was observational in design and was not intended to establish causal relationships between specific occupational factors and particular diseases; rather, it assessed statistical associations based on the available data.

2. MATERIALS AND METHODS

2.1 Dynamic risk assessment under extreme temperature conditions

Construction activities in the Republic of Kazakhstan are predominantly performed outdoors and are therefore exposed to extreme climatic conditions, which substantially increase occupational risks. Low and high ambient temperatures, wind speed, humidity, and solar radiation directly affect workers' physical condition, work performance, and safety. Exposure to low temperatures reduces motor function and coordination, whereas high temperatures contribute to heat stress, dehydration, and fatigue, thereby increasing the likelihood of occupational injuries.

To improve the effectiveness of OHSMS, a dynamic risk assessment approach was integrated into the OHSMS. During the planning stage, occupational hazards, weather conditions, precipitation, ice formation, and the likelihood of exposure to extreme temperatures were considered to determine appropriate preventive measures.

A general hygienic assessment of occupational environmental and work process factors was conducted based on the results of workplace assessments of working conditions for the main construction occupations.

Preventive measures aimed at minimizing or eliminating identified hazards were implemented according to the assessment results, followed by a reassessment of the residual risk. In addition, a checklist-based approach was used to evaluate compliance with OHS requirements. The proposed methodology enables the timely identification of hazardous working conditions and the adaptation of preventive measures

to changing climatic conditions, thereby reducing the risk of weather-related occupational injuries.

To visually represent the hazards, potential consequences, and risk control measures associated with exposure to extreme temperatures, a bow-tie diagram was developed (Figure 1). The prescribed safety measures for outdoor work under different environmental conditions are summarized in Table 1.

Based on compliance with the prescribed safety measures and the level of exposure to extreme temperature conditions, occupational risk was classified into five levels, as presented in Table 2.

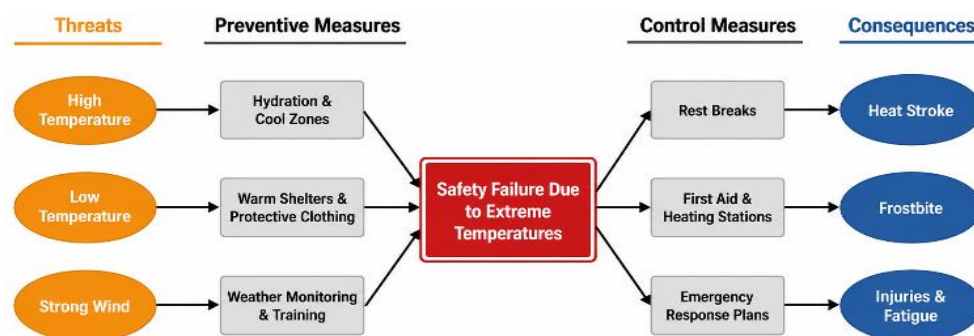


Figure 1. Bow-tie diagram for risk assessment under extreme temperatures

Table 1. Prescribed safety measures for outdoor work under different environmental conditions

Temperature Conditions	Hazards	Safety Measures	Notes
High temperatures (>32.5 °C, particularly between 12:00 and 16:00)	Heat stress, dehydration, fatigue, reduced concentration	• Reduce shift duration and working hours during hot weather. • Provide work-rest cycles with breaks every 15–20 min (minimum 10–12 min). • Ensure access to drinking water (12–15 °C). • Provide cooling and rest areas (shade, fans). • Use light-colored work clothing and head protection. • Provide preventive nutritional support.	Outdoor work without heat protection should not exceed 1.5–2 h without cooling. When wearing heat-protective coveralls, the maximum continuous working time is 4–5 h.
Low temperatures (<–30 °C, down to –40 °C)	Hypothermia, frostbite, impaired motor function, increased risk of errors	• Limit exposure time outdoors. • Provide heated shelters and warming breaks. • Wear multilayer insulated protective clothing. • Protect the face and respiratory tract. • Monitor workers' physical workload.	Outdoor work is prohibited at temperatures below –40 °C without appropriate personal protective equipment (PPE) for face protection.

Table 2. Occupational risk levels associated with exposure to extreme temperature conditions

Risk Level	Percentage of Requirements Met, %	Description
1	>91%	Acceptable risk
2	71–90%	Low risk
3	51–70%	Moderate risk
4	31–50%	High risk
5	≤30%	Very high risk

Following the implementation of the prescribed safety measures, continuous monitoring and periodic review of risk control measures were carried out. Occupational risk assessment was performed based on compliance with regulatory requirements and the level of exposure to extreme temperature conditions.

Following the occupational risk assessment, the results were used to develop corrective actions and support continuous dynamic hazard assessment throughout the work shift. Organizational and technical control measures were adjusted according to the identified risk level to reduce workers'

exposure to hazardous factors. Particular emphasis was placed on the transition from static risk assessment to dynamic risk management under changing environmental conditions, especially the extreme temperatures characteristic of construction sites in the Republic of Kazakhstan. This approach enables real-time monitoring of climatic conditions and facilitates the timely implementation of preventive measures to ensure safe working conditions.

2.2 Methodology for occupational risk assessment

The methodological framework of the study was based on an Occupational Risk Assessment System (ORAS) employing a two-dimensional risk matrix that incorporated two key parameters: the likelihood of hazardous events and the severity of their consequences. The likelihood was classified into three levels (low, medium, and high), while consequences were categorized as minor, moderate, and severe. The combination of these parameters was used to determine the overall risk level and to select appropriate risk control measures.

Considering the elevated risks associated with construction activities in the Republic of Kazakhstan, the study applied the

methodology established by Order No. 363 of the Minister of Labour and Social Protection of the Population of the Republic of Kazakhstan [21]. In addition, dynamic occupational risk assessment (DORA) was implemented to enable real-time safety monitoring before work commenced, throughout the work shift, whenever working conditions changed, and following the occurrence of potentially hazardous situations.

The dynamic assessment process consisted of five stages: hazard identification, risk assessment, implementation of control measures, residual risk assessment, and documentation of the assessment results. The stages of the DORA applied in this study are presented in Figure 2.

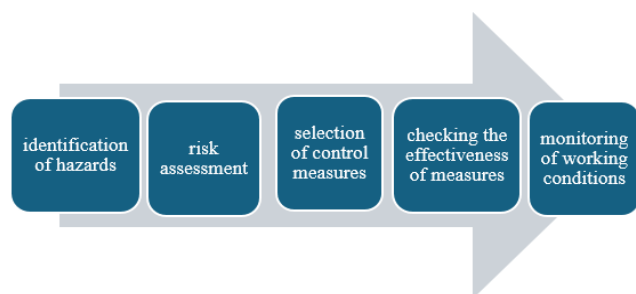


Figure 2. The stages of the dynamic occupational risk assessment (DORA)

A risk matrix was used to quantitatively assess and prioritize occupational hazards. Particular attention was paid to high-risk activities, including work at height, which require a mandatory work permit in accordance with national regulations. To standardize the hazard identification process and minimize the likelihood of overlooking significant risks, a comprehensive checklist of hazardous and harmful factors was employed.

The likelihood of hazardous events was evaluated based on actual working conditions, equipment condition, workers' competence, and external factors, including weather conditions. The severity of potential consequences was assessed according to the expected injury severity, duration of exposure, and potential impact on workers' health.

The approach to occupational risk assessment was based on a previously published and validated risk-oriented methodology for the analysis of working conditions [22].

The results of the DORA were documented using risk assessment forms and submitted to an expert panel for further evaluation. Additional control documentation included work permits for high-risk activities and hazard notification forms used to record newly identified hazards.

The proposed system enables the systematic identification and control of technical, organizational, and human-related hazards, facilitates rapid responses to changing environmental conditions, minimizes occupational injuries through continuous monitoring, and promotes the development of a proactive safety culture. The integration of quantitative risk assessment with standardized control procedures demonstrates the effectiveness of a systematic approach that can be applied to construction projects in the Republic of Kazakhstan and other developing countries with similar climatic conditions.

Statistical analysis included correlation and linear regression analyses. The strength of associations between the studied variables was assessed using Pearson's correlation coefficient (r). Statistical significance was established at $p < 0.05$. The goodness-of-fit of the regression models was evaluated using the coefficient of determination (R^2). Data

analysis was performed using Python 3.12.

Independent variables included exposure variables derived from workplace assessment and certification data. Depending on the completeness of the available data, the following variables were used: actual values of occupational exposure factors recorded in workplace assessment protocols; shift-average exposure levels; 8-hour equivalent noise and vibration levels, where the available data allowed recalculation; occupational condition classes; binary variables indicating exceedance of hygienic standards; integrated exposure indices; and indicators of the severity and intensity of the work process. Categorical or ordinal variables reflecting the occupational condition class and the occurrence of hygienic standard exceedances were also included in the analysis. Thus, the statistical models used standardized exposure variables that were comparable across workers and occupational groups rather than isolated and heterogeneous assessments of working conditions.

The dependent variables were workers' morbidity indicators confirmed by temporary disability certificates, including the presence or absence of respiratory diseases, musculoskeletal disorders, hearing impairment, and other registered health outcomes. Exposed and control groups were formed based on the values of the exposure variables. For example, workers employed under occupational conditions classified as above the permissible level or with exposure exceeding the maximum permissible concentration (MPC) or maximum permissible level (MPL) were assigned to the exposed group, whereas workers with permissible working conditions were assigned to the control group.

Standard epidemiological measures were used to quantitatively assess the associations between exposure to hazardous occupational factors and registered morbidity among workers. The relative risk (RR) [23] was calculated as the ratio of the risk of developing the outcome of interest in the group of workers exposed to the studied factor to the corresponding risk in the control group:

$$RR = [a/(a+b)] / [c/(c+d)] \quad (1)$$

where,

a: number of workers with the outcome of interest in the exposed group;

b: number of workers without the outcome in the exposed group;

c: number of workers with the outcome in the control group;

d: number of workers without the outcome in the control group.

To quantitatively characterize the proportion of disease cases among exposed workers statistically associated with the studied exposure, the etiologic fraction (EF) [23] was calculated as follows:

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

To assess the statistical uncertainty of the relative risk estimates, 95% confidence intervals (95% CI) were calculated using logarithmic transformation of RR [24]. The standard error of $\ln(RR)$ was calculated as:

$$SE[\ln(RR)] = \sqrt{1/a - 1/(a+b) + 1/c - 1/(c+d)} \quad (3)$$

The 95% confidence interval for RR was calculated as:

$$95\% \text{ CI} = \exp\{\ln(RR) \pm 1.96 \times SE[\ln(RR)]\} \quad (4)$$

An RR estimate was considered statistically different from 1 when the corresponding 95% CI did not include 1.0.

RR and EF were used together with the results of the correlation analysis to characterize the strength of statistical associations and identify priority occupational exposure factors. RR and EF were interpreted as measures of association and the potential contribution of exposure to registered morbidity rather than as evidence of a causal relationship, because the study had an observational design and did not provide complete control for potential confounding factors.

2.3 Dynamic occupational risk assessment tools

As part of the study, a comprehensive set of DORA tools was developed and tested to systematically monitor compliance with OHS and industrial safety requirements during construction activities. The developed toolkit includes safety checklists for work at height and outdoor operations, as well as a daily pre-shift risk assessment form. Each tool was designed for a specific purpose and addresses particular aspects of workplace safety, thereby establishing a multi-level risk assessment system capable of promptly identifying changes in working conditions and supporting timely management decision-making.

The developed set of tools was piloted at a construction enterprise in the Republic of Kazakhstan during 2025. The study included 395 workers employed in the main construction occupations. Data collection included instrumental measurements of occupational environmental factors, analysis of 192 temporary disability certificates, and assessment of compliance with safety requirements based on 81 checklist items (37 for work at height and 44 for outdoor work).

The study, which involved the retrospective use of previously collected data on working conditions and workers' morbidity, was reviewed and approved by the Ethics Committee of the Republican Research Institute for Occupational Safety of the Republic of Kazakhstan (Protocol No. 6 dated June 20, 2026). The Ethics Committee granted a waiver of the requirement to obtain individual informed consent for the retrospective analysis of anonymized data. All data were anonymized prior to analysis; information that could identify individual workers was neither used nor disclosed.

Pilot Enterprise No. 1. The total workforce of Pilot Enterprise No. 1 consisted of 262 employees, including 27 women, accounting for 10.31% of the total workforce. The administrative and managerial staff (hereinafter, AMS) comprised 37 employees. The number of employees in the core production workforce was 225.

In 2025, temporary disability cases confirmed by temporary disability certificates were registered among 97 employees of the enterprise. Of the total number of affected workers, 11 belonged to the control group, whereas 86 belonged to the exposed group. Thus, the majority of registered temporary disability cases occurred among workers employed in construction occupations.

Analysis of the distribution of workers by length of service showed that the largest group consisted of employees with 0-5 years of work experience (62 workers). A total of 27 workers had 6-10 years of work experience, 5 workers had 11-15 years, and 3 workers had more than 15 years of work experience.

During the study period, injuries were registered among 17 employees of the enterprise. These data demonstrate the

occurrence of temporary disability and occupational injuries among the enterprise workforce and may be used for subsequent comparative analysis of morbidity indicators between the exposed and control groups, including the assessment of RR and EF.

Pilot Enterprise No. 2. The total workforce of Pilot Enterprise No. 2 consisted of 133 employees, including 11 women, accounting for 8.27% of the total workforce. The administrative and managerial staff (AMS) comprised 25 positions. The number of employees in the core production workforce was 108.

During the analyzed period in 2025, temporary disability cases documented by temporary disability certificates were registered among 95 employees. Of these, 5 cases occurred in the control group, whereas 90 cases of temporary disability were registered in the exposed group.

Analysis of the distribution of workers by length of service showed that the largest group consisted of employees with 0-5 years of work experience (60 workers). A total of 27 workers had 6-10 years of work experience, 6 workers had 11-15 years, and 2 workers had more than 15 years of work experience.

During the study period, occupational and other injuries were registered among 17 employees of the enterprise. The findings indicate the occurrence of temporary disability and injuries among the enterprise workforce, with the majority of registered temporary disability cases occurring in the exposed group.

To assess compliance with safety requirements during work at height, a checklist was developed incorporating the technical, organizational, and personnel-related components of the OHSMS. The structure and content of the checklist are presented in Table 3.

The instrument was developed based on an analysis of the current OHS legislation of the Republic of Kazakhstan and internationally recognized best practices in fall risk management. The checklist is intended for comprehensive auditing of OHSMS and for identifying organizational and technical factors that influence occupational risk.

The checklist is organized into three main sections: (i) technical requirements for equipment and protective devices, (ii) organizational and management processes supporting work-at-height safety, and (iii) personnel training and competency requirements.

The first section evaluates the technical preparedness of an enterprise for the safe execution of work at height. The assessment includes verification of technical specifications for equipment and protective devices, availability of personal protective equipment (PPE), condition and completeness of fall protection systems, compliance of anchor devices with regulatory requirements, implementation of collective protective measures, and the safe operation of mobile elevating work platforms (MEWPs). Particular attention is given to continuous fall protection, equipment integrity, and measures to prevent falls of both workers and objects from height.

The second section focuses on the effectiveness of organizational and management processes. It includes criteria related to the availability of corporate standards and operating procedures, implementation of work permit and risk assessment systems, development of work method statements and emergency response plans, management and inspection of fall protection equipment, and periodic review of regulatory documentation based on operational experience and incident investigations. The section also evaluates personnel

competence, including the appointment of responsible persons, worker training and certification programs, and compliance with corporate safety requirements by contractors.

Each checklist item is evaluated as either compliant or non-compliant with the established requirements, enabling quantitative assessment of the implementation of mandatory

safety measures. The application of this checklist provides a standardized approach to safety auditing, improves the objectivity of OHSMS evaluations, and facilitates the identification of priority areas for improving fall prevention measures.

Table 3. Summary of checklists for ensuring safety during work at height and outdoor work

Requirement Block	Key Control Parameters	Source of Details
1. Technical readiness of equipment and PPE	-Compliance of lifting equipment, scaffolding, and anchor points with technical requirements and verification of their serviceability; -Availability, completeness, and visual inspection of personal fall protection systems (harnesses, lanyards, energy absorbers); - Adaptation of PPE and tools to current weather conditions (wind, precipitation, temperature, dust); - Resistance of temporary structures and road surfaces to climatic factors -Fencing and marking of hazardous areas, taking into account visibility and weather-related risks;	Appendix, Table A1 (items 1-8) Table A2 (items 1-15, 30-34)
2. Work-zone organization and collective protection	- Measures to prevent falling objects and ensure safe handling and movement of tools; -Provision of adequate welfare facilities (drinking water, shelters, heating/cooling facilities); -Safe routes for the movement of personnel and vehicles - Availability of work execution plans, work permits, and corporate safety standards;	Appendix, Table A1 (item 7) Table A2 (items 11-13, 24-29, 38-43)
3. Documentation, planning, and risk management	- Risk assessment with mandatory consideration of microclimatic hazards and weather-related work limits; -Emergency response plans and adjustment of work schedules; - Verification of the compliance of design documentation with site-specific conditions -Targeted safety briefings on the specific risks associated with outdoor work and work at height;	Appendix, Table A1 (organizational block, item 2) Table A2 (items 16-19, 22)
4. Personnel: competence, authorization, and health monitoring	-Verification of knowledge, certification, and authorization to perform work, including contractors; - Monitoring workers' health status before authorization to work (heatstroke, hypothermia); -Information on hazardous areas and speed restrictions	Appendix, Table A1 (organizational block, item 3) Table A2 (items 20-21, 23, 35-37, 40-41, 44)

Note: The complete checklists, comprising 37 items for work at height and 44 items for outdoor work, are provided in the Appendix (Tables A1 and A2, respectively). In this table, overlapping items related to the inspection of PPE and equipment, assessment of weather conditions, and safety briefings have been consolidated into unified thematic blocks.

To assess compliance with safety requirements during outdoor construction activities, a Dynamic Risk Assessment Checklist was developed and applied (Appendix, Table A2). Unlike conventional static checklists, this instrument is designed to provide rapid assessment of changing workplace conditions and is intended for use immediately before work begins or whenever significant weather changes occur. The checklist comprises seven key assessment domains: the technical condition of equipment and lifting devices; the condition of construction structures and engineering facilities; the integrity of fall protection systems; the availability and condition of collective and PPE; worksite organization; documentation and procedural compliance; and personnel preparedness for working under specific weather conditions. In total, the checklist includes 44 assessment items, providing comprehensive coverage of all critical safety aspects associated with outdoor construction work.

The instrument is intended for the systematic identification of hazards associated with the technical condition of equipment, work organization, personnel preparedness, and the influence of weather conditions on occupational risk. Its application enables the assessment of occupational risk during outdoor work while accounting for occupational and climatic factors that may adversely affect the safety of work activities.

The assessment items included in the checklist cover the entire cycle of work planning and execution. The evaluation

addresses the technical condition of equipment, lifting devices, temporary construction structures, fall protection systems, vehicles, and engineering infrastructure, as well as their suitability for operation under adverse meteorological conditions.

A separate group of criteria assesses organizational and planning measures, including the availability of approved design and permit documentation, occupational risk assessment results, and mechanisms for adapting work processes to changing weather conditions.

The checklist also evaluates the provision of PPE and collective protective measures, the condition of the working environment, the availability of communication facilities and first-aid resources, and the implementation of measures aimed at minimizing the adverse effects of unfavorable climatic conditions on workers' health.

Particular attention is given to personnel preparedness and compliance with OHS requirements, including the completion of safety briefings, workers' awareness of workplace hazards, and verification of their readiness to perform work under adverse environmental conditions.

The application of this checklist provides a comprehensive assessment of occupational safety performance, facilitates the identification of critical non-conformities, and supports the development of corrective actions aimed at reducing the risk of occupational injuries and work-related diseases.

3. RESULTS AND DISCUSSION

A comparative analysis of the two pilot enterprises revealed differences in the structure of occupational risks. At Pilot Enterprise 1, the most pronounced associations were related to physical workload and microclimatic conditions, whereas at Pilot Enterprise 2, chemical aerosols and dust pollutants were the predominant risk factors.

Analysis of the data obtained from Pilot Enterprise 1 and Pilot Enterprise 2 demonstrated differences in the levels of exposure to hazardous occupational environmental factors, including workload and work intensity, air temperature, noise levels, and dust concentrations. These associations were assessed using correlation coefficients between occupational exposure indicators and morbidity outcomes across different body systems.

At Pilot Enterprise 1, the most pronounced associations were identified between work intensity and upper respiratory tract diseases ($r = 0.816$; $R^2 = 0.666$; $p < 0.001$) and between air temperature and upper respiratory tract diseases ($r = 0.818$; $R^2 = 0.669$; $p < 0.001$). In addition, statistically significant associations were identified between workload severity and optic nerve disorders ($r = 0.656$; $R^2 = 0.430$; $p < 0.01$), as well as between exposure to welding aerosols and musculoskeletal disorders ($r = 0.619$; $R^2 = 0.383$; $p < 0.01$).

At Pilot Enterprise 2, the structure of associations was different. The highest correlation coefficients were observed between quartz-containing inorganic dust and respiratory diseases ($r = 0.970$; $R^2 = 0.942$; $p < 0.001$), between exposure to sulfur dioxide and sulfuric acid vapors and respiratory diseases ($r = 0.930$; $R^2 = 0.870$; $p < 0.001$), and between carbon monoxide exposure and respiratory diseases ($r = 0.804$; $R^2 = 0.646$; $p < 0.001$). Significant associations were also identified between inorganic silicate dust and upper respiratory tract diseases ($r = 0.776$; $R^2 = 0.602$; $p < 0.001$), and between air temperature and musculoskeletal disorders ($r = 0.591$; $R^2 = 0.349$; $p < 0.05$).

The strongest statistical associations were obtained for chemical factors at Pilot Enterprise 2. The association between quartz-containing inorganic dust and respiratory diseases was particularly pronounced ($r = 0.970$; $R^2 = 0.942$). The obtained R^2 value means that a significant proportion of the variability of the indicator under consideration in the study sample is statistically associated with changes in the level of this factor.

The strong association obtained between quartz-containing dust and respiratory diseases ($r = 0.970$; $R^2 = 0.942$) is consistent with the results of studies of construction workers, in which exposure to respirable silica and other dust aerosols was considered one of the main occupational risk factors for respiratory diseases [25]. This result is also consistent with studies in which construction workers exposed to dust and silica demonstrated reduced lung function parameters compared with control groups [26].

The similarity of the results of the present study to published data has practical significance. Unlike Enterprise 1, where respiratory indicators were more closely associated with work intensity and temperature, Enterprise 2 demonstrated a more pronounced dependence on the chemical composition of workplace air. A possible explanation is the difference in technological operations and the composition of pollutants. Therefore, preventive measures should be focused not only on the overall indicator of "dustiness," but also on the chemical composition of aerosols, the effectiveness of local ventilation, exposure duration, and the use of respiratory protective

equipment.

The strong association between exposure to sulfur dioxide and sulfuric acid vapors and respiratory diseases ($r = 0.930$; $R^2 = 0.870$) further supports the relevance of chemical exposures at Pilot Enterprise 2. However, this finding should not be interpreted as evidence of a direct causal effect.

For both enterprises, a significant association was identified between workload severity and intensity and musculoskeletal disorders ($r = 0.780$; $R^2 = 0.608$; $p < 0.01$). This finding is consistent with the multifactorial nature of work-related musculoskeletal disorders. Physical workload among construction workers is usually combined with lifting heavy loads, repetitive movements, awkward working postures, and exposure to vibration. Therefore, the identified association should be interpreted as reflecting combined ergonomic exposure rather than an independent effect of a single workload severity indicator.

A significant association was also identified between occupational noise and hearing impairment ($r = 0.820$; $R^2 = 0.672$; $p < 0.001$). This result is consistent with generally accepted data on occupational noise as a risk factor for hearing loss. The World Health Organization considers prolonged exposure to high noise levels to be a risk factor for temporary and permanent hearing impairment, while the International Labour Organization classifies noise and vibration as key physical occupational hazards [27].

At the same time, the strength of the statistical association does not allow the conclusion that all registered hearing impairments are caused exclusively by occupational noise. The results may be influenced by workers' age, length of occupational experience, individual susceptibility, use of PPE, and exposure to noise outside the workplace. Therefore, further risk assessment should take exposure duration and individual characteristics of workers into account.

One of the specific features of the present study is the need to interpret occupational risks taking into account the climatic conditions of Kazakhstan. In construction, the climatic factor is of particular importance because a significant proportion of work is performed outdoors, while the duration and intensity of exposure to temperature, wind, and solar radiation vary substantially throughout the year.

At Enterprise 1, air temperature demonstrated a strong positive correlation with upper respiratory tract diseases ($r = 0.818$; $R^2 = 0.669$; $p < 0.001$), whereas at Enterprise 2, temperature was associated with musculoskeletal disorders ($r = 0.591$; $R^2 = 0.349$; $p < 0.05$). A possible explanation for the differences is the unequal structure of technological operations, which determines both the range of occupational pollutants and the nature of physical workload. At Enterprise 1, operations accompanied by significant physical workload, noise, welding aerosols, and exposure to microclimatic conditions predominated, whereas at Enterprise 2, processes accompanied by the formation of inorganic dust and gaseous chemical pollutants played a significant role. Therefore, differences in the correlation coefficients between the enterprises should be regarded as reflecting differences in occupational exposure rather than as a contradiction between the results.

At high temperatures, the combination of heavy physical work, protective clothing, and limited ventilation may increase heat load and reduce functional capacity. During the cold period, low temperatures and wind may increase physical workload and make operations more difficult, particularly during work at height and when using hand tools. The

International Labour Organization emphasizes that changing climatic conditions are already affecting workers' safety and health, with heat stress being considered one of the most significant emerging occupational risks.

Thus, the identified associations with temperature should be interpreted taking into account the seasonal variability of climatic conditions. However, the present study did not include a separate assessment of seasonal subgroups; therefore, the effect of temperature cannot be separated from accompanying factors, including physical workload, work-shift duration, and the nature of the technological operation.

Correlation analysis of the associations between hazardous occupational factors and worker morbidity is presented in Table 4.

Assessment of relative risk and EF is presented in Table 5.

The source data and detailed calculations of RR and EF are

presented in the Appendix (Tables A3 and A4).

The 95% confidence intervals for the RR estimates were relatively wide and included 1.0, reflecting the limited number of disease-specific cases, particularly in the control groups. Therefore, although the point estimates of RR indicate increased risk in the exposed groups, these estimates should be interpreted with caution as exploratory measures of association rather than as statistically confirmed effects.

At Pilot Enterprise No. 1, the highest relative risk was identified for musculoskeletal disorders (RR = 2.30), as well as for upper respiratory tract diseases (RR = 2.22). The EF for these disease groups was 56.52% and 54.95%, respectively, corresponding to a high degree of association with occupational factors. This means that more than half of the cases of these diseases may potentially be associated with exposure to occupational factors.

Table 4. Correlation analysis of associations between hazardous occupational factors and worker morbidity (pilot enterprises 1 and 2)

Hazardous Occupational Factor	Morbidity Outcome	Pearson Correlation Coefficient (r)	Coefficient of Determination (R ²)	Significance Level (p)	Enterprise
Workload severity	Optic nerve	0.656	0.430	<0.01	1
Low-fibrogenic aerosols (welding dust)	Musculoskeletal disorders	0.619	0.383	<0.01	1
Work intensity	Upper respiratory tract diseases	0.816	0.666	<0.001	1
Air temperature	Upper respiratory tract diseases	0.818	0.669	<0.001	1
Air temperature	Musculoskeletal disorders	0.591	0.349	<0.05	2
Inorganic silicate dust (20-70%)	Upper respiratory tract diseases	0.776	0.602	<0.001	2
Work intensity	Hearing impairment	0.491	0.241	<0.05	2
Quartzite (inorganic dust)	Respiratory diseases	0.970	0.942	<0.001	2
Sulfur dioxide and sulfuric acid (vapors)	Respiratory diseases	0.930	0.870	<0.001	2
Sulfur dioxide and sulfuric acid (vapors)	Gastrointestinal tract	0.880	0.774	<0.001	2
Carbon monoxide	Respiratory diseases	0.804	0.646	<0.001	2
Occupational noise	Hearing impairment (sensorineural)	0.820	0.672	<0.001	1.2
Workload severity and intensity	Musculoskeletal disorders	0.780	0.608	<0.01	1.2
Hydrofluoric acid and phosphoric acid aerosols	Respiratory diseases	0.540	0.292	<0.05	2
Nitrogen dioxide	Respiratory diseases	0.400	0.160	<0.05	2

Note: R² - coefficient of determination, characterizing the proportion of morbidity variance explained by the respective factor.

Statistical significance levels: p < 0.05; p < 0.01; p < 0.001 (two-tailed test).

Correlation analysis identifies statistical associations but does not establish a direct causal relationship without accounting for confounding variables.

A dash (-) indicates the absence of a statistically significant association at p > 0.05.

Table 5. Assessment of relative risk and etiologic fraction (EF)

Disease Group	Upper Respiratory Tract Diseases	Hearing Impairment	Disease Group	Visual Disorders	Skin Diseases	Musculoskeletal Disorders
Pilot Enterprise No. 1						
Relative risk, RR	2.22	1.64	1.15	-	1.48	2.30
95% CI for RR	0.55–8.95	0.22–12.47	0.15–9.09	-	0.19–11.34	0.31–16.99
Etiologic fraction, EF, %	54.95%	39.02%	13.04%	-	32.43%	56.52%
Association category	High	Moderate	Low	-	Low	High
Pilot Enterprise No. 2						
Relative risk, RR	4.63	3.94	-	4.17	-	3.94
95% CI for RR	0.65–32.89	0.55–28.20	-	0.58–29.76	-	0.55–28.20
Etiologic fraction, EF, %	78.40%	74.62%	-	76.02%	-	74.62%
Association category	Very high	Very high	-	Very high	-	Very high

Note: RR and EF were interpreted according to the adopted classification criteria for the degree of association with occupational factors. The 95% confidence intervals (95% CI) characterize the statistical precision of the RR estimates. Confidence intervals including 1.0 indicate that the corresponding RR estimate is not statistically different from 1 at the 0.05 significance level.

For hearing impairment, a moderate level of risk was established ($RR = 1.64$), with an EF of 39.02%, indicating a notable contribution of occupational factors to the development of this pathology. For skin diseases ($RR = 1.48$; EF = 32.43%) and gastrointestinal diseases ($RR = 1.15$; EF = 13.04%), a lower degree of association with working conditions was observed. According to the criteria presented, the etiologic fraction for these diseases was characterized as low.

At Pilot Enterprise No. 2, the point estimates of relative risk were higher than those observed at Pilot Enterprise No. 1, although the corresponding 95% confidence intervals were wide and included 1.0. The highest RR values were recorded for upper respiratory tract diseases ($RR = 4.63$; EF = 78.40%), visual disorders ($RR = 4.17$; EF = 76.02%), and hearing impairment ($RR = 3.94$; EF = 74.62%). Musculoskeletal disorders were also characterized by a high relative risk ($RR = 3.94$) and a high EF (EF = 74.62%). All of these indicators correspond to the category of very high association with occupational factors.

Thus, the comparative analysis showed higher point estimates of RR at Pilot Enterprise No. 2 than at Enterprise No. 1, particularly for upper respiratory tract diseases, hearing impairment, visual disorders, and musculoskeletal disorders. However, the wide 95% confidence intervals indicate considerable statistical uncertainty, and these differences should therefore be interpreted cautiously. Particularly pronounced associations with occupational factors were observed for upper respiratory tract diseases, hearing impairment, visual disorders, and musculoskeletal disorders. RR values ranging from 3.94 to 4.63 indicate a several-fold increase in the risk of these outcomes, while EF values of 74.62–78.40% indicate that a substantial proportion of the identified morbidity may be associated with exposure to occupational environmental factors.

Overall, the results indicate the need to prioritize preventive and occupational hygiene measures at Pilot Enterprise No. 2, particularly those aimed at controlling occupational exposures associated with respiratory diseases, hearing impairment, visual disorders, and musculoskeletal disorders. At Enterprise No. 1, priority should be given to the prevention of upper respiratory tract diseases and musculoskeletal disorders, for which the highest relative risk and EF values were identified.

Influence of the regulatory and legal framework on occupational risk assessment: interpretation of the results should be carried out taking into account the existing occupational safety system of the Republic of Kazakhstan. In particular, work at height is regulated by the Rules for Ensuring Safety and Occupational Safety during Work at Height, approved by Order No. 109 of the Minister of Labour and Social Protection of the Population of the Republic of Kazakhstan [28]. The document establishes the procedure for ensuring safety during work at height and defines work at height as an activity in which a worker is located at a height or depth of 1.3 m or more under certain conditions.

The regulatory and legal requirements of the Republic of Kazakhstan establish the organizational conditions under which occupational risks are managed and therefore should be taken into account when interpreting the results obtained. The established procedures for authorization to perform work, identification and assessment of hazards, organization of safe work, and use of PPE are aimed at preventing injuries and reducing the likelihood of hazardous occupational events. In this regard, a high occupational risk category for certain types

of work should not be regarded as evidence of the absence or ineffectiveness of preventive measures. On the contrary, it may reflect a combination of high potential severity of consequences and continued exposure to hazardous and harmful occupational factors even when control measures prescribed by regulatory requirements are in place. At the same time, the present study does not allow the independent effect of the degree of compliance with regulatory requirements on occupational morbidity and occupational injury indicators to be quantified, as such an assessment requires a separate analysis of the actual level of compliance with the requirements, the effectiveness of the control measures applied, and accompanying risk factors.

This is particularly relevant to roofing work. Analysis of the hazard map showed that roofers are simultaneously exposed to the risk of falls from height, wind loads, temperature exposure, physical workload, and noise. This combination of factors explains the classification of the occupation as having a very high occupational risk. In accordance with the modern international concept of construction safety management, the control of such risks should be based on the hierarchy of preventive measures, beginning with hazard elimination and engineering controls and supplemented by organizational measures and PPE. The identified structure of occupational risks is consistent with the revised ILO Code of Practice on Safety and Health in Construction, which emphasizes the multiple nature of hazards in the construction sector and the need for systematic occupational risk management [29].

Thus, the national regulatory framework forms the organizational context in which occupational risks are controlled. For Kazakhstan, regulatory requirements should therefore be combined with a risk-oriented approach accounting for actual exposure levels, seasonal variation, and the characteristics of specific technological operations.

In the present study, the same principle is confirmed by the differences between the two enterprises. At one site, the priority factors are physical workload, noise, welding aerosols, and microclimatic conditions, whereas at the other, dust and gaseous chemical pollutants predominate. Therefore, a single list of hazards does not provide an adequate risk assessment without taking into account the specific working environment.

The combination of occupational and climatic factors further supports the use of dynamic rather than predominantly static risk assessment. Under the climatic conditions of Kazakhstan, exposure may vary considerably over time because of seasonal temperature changes, wind, and changing technological operations. Dynamic assessment is therefore particularly relevant to outdoor and work-at-height activities and to operations involving dust, gases, noise, and vibration.

The practical implications of these findings differ between the two enterprises. At Enterprise 1, priority should be given to reducing physical and ergonomic workload, controlling occupational noise and welding aerosols, and seasonal monitoring of microclimatic conditions. At Enterprise 2, priority measures should include control of dust and gaseous pollutants, improved ventilation, evaluation of respiratory protective equipment effectiveness, and regular occupational exposure monitoring.

4. CONCLUSIONS

The study demonstrated that occupational risk assessment in the construction sector of the Republic of Kazakhstan

should account for the combined influence of occupational, organizational, and climatic factors. The developed dynamic risk assessment approach integrates hazard identification, residual risk assessment, compliance monitoring, and consideration of changing working conditions, including extreme temperatures.

In the two pilot enterprises, statistically significant associations were identified between occupational exposure characteristics and workers' morbidity indicators. The dominant risk profiles differed between the sites: chemical aerosols and dust-related exposures were more prominent at Enterprise 2, whereas physical workload, noise, and microclimatic factors were more relevant at Enterprise 1. These differences support differentiated occupational risk management adapted to site-specific technological and exposure conditions. Climatic conditions should additionally be considered as a variable component of occupational risk during outdoor construction work.

The developed checklists for work at height and outdoor work, together with shift-based dynamic risk assessment, provide a practical framework for identifying critical non-conformities and adjusting preventive measures to changing working conditions. The findings support the integration of occupational exposure monitoring with dynamic risk assessment as a basis for proactive safety management in construction.

Interpretation of the results should take into account the observational design, limited sample size, and incomplete control for potential individual-level confounding factors. The identified statistical associations do not establish causal relationships between individual occupational factors and diseases; therefore, the findings should primarily be considered as a basis for hypothesis generation and improvement of occupational risk management.

Future research should include prospective multicenter studies with larger samples, repeated occupational exposure measurements, and multivariable models accounting for individual and seasonal factors. Further development should also focus on digitalizing dynamic risk assessment by integrating occupational exposure monitoring with meteorological data to enable early detection of critical changes in working conditions.

ACKNOWLEDGMENT

This study was conducted within the framework of the scientific and technical program "Working conditions and occupational risks: classification, categories and grouping criteria in the framework of the transition to a «green economy» (IRN BR22182667), supported through program-targeted financing and implemented by the Republican Research Institute for Occupational Safety and Health under the Ministry of Labor and Social Protection of the Population of the Republic of Kazakhstan.

REFERENCES

- [1] Suárez Sánchez, F.A., Carvajal Peláez, G.I., Catalá Alís, J. (2017). Occupational safety and health in construction: A review of applications and trends. *Industrial Health*, 55(3): 210-218. <https://doi.org/10.2486/indhealth.2016-0108>
- [2] Feng, J., Gao, X., Li, H.J., Liu, B.J., Tang, X.Y. (2024). A science mapping approach-based review of construction workers' safety-related behavior. *Buildings*, 14(4): 1162. <https://doi.org/10.3390/buildings14041162>
- [3] Kineber, A.F., Antwi-Afari, M.F., Elghaish, F., Zamil, A.M.A., Alhusban, M., Qaralleh, T.J.O. (2023). Benefits of implementing occupational health and safety management systems for the sustainable construction industry: A systematic literature review. *Sustainability*, 15(17): 12697. <https://doi.org/10.3390/su151712697>
- [4] Sadeghi, H., Cheung, C.M., Yunusa-Kaltungo, A., Manu, P. (2025). A systematic review of occupational safety and health in modular integrated construction. *Safety Science*, 189: 106897. <https://doi.org/10.1016/j.ssci.2025.106897>
- [5] Yin, J.J., Alias, A.H., Haron, N.A., Abu Bakar, N. (2023). A bibliometric review on safety risk assessment of construction based on CiteSpace software and WoS database. *Sustainability*, 15(15): 11803. <https://doi.org/10.3390/su151511803>
- [6] Teizer, J. (2015). Status quo and open challenges in vision-based sensing and tracking of temporary resources on infrastructure construction sites. *Advanced Engineering Informatics*, 29(2): 225-238. <https://doi.org/10.1016/j.aei.2015.03.006>
- [7] Saif, W., Williams, T., Wong, C., Dobos, J., Martinez, P., Kassem, M. (2024). Digital twin for safety on construction sites: A real-time risk monitoring system combining wearable sensors and 4D BIM. In *2024 European Conference on Computing in Construction*, Chania, Greece, pp. 526-533. <https://doi.org/10.35490/EC3.2024.252>
- [8] Babalola, A., Manu, P., Cheung, C., Yunusa-Kaltungo, A., Bartolo, P. (2023). A systematic review of the application of immersive technologies for safety and health management in the construction sector. *Journal of Safety Research*, 85: 66-85. <https://doi.org/10.1016/j.jsr.2023.01.007>
- [9] Bekmagambetov, A., Rakhmetova, A., Yedilbayeva, L., et al. (2025). A study on causal relationships between working conditions and occupational diseases: A case study of a phosphorus plant in Kazakhstan. *International Journal of Safety and Security Engineering*, 15(5): 973-985. <https://doi.org/10.18280/ijss.150511>
- [10] Neal, A., Griffin, M.A. (2006). A study of the lagged relationships among safety climate, safety motivation, safety behavior, and accidents at the individual and group levels. *Journal of Applied Psychology*, 91(4): 946-953. <https://doi.org/10.1037/0021-9010.91.4.946>
- [11] Fang, D., Wu, H. (2020). Development of a Safety Culture Interaction (SCI) model for construction projects. *Safety Science*, 57: 1138-149. <https://doi.org/10.1016/j.ssci.2013.02.003>
- [12] Phinias, R.N. (2023). Benefits and challenges relating to the implementation of health and safety leading indicators in the construction industry: A systematic review. *Safety Science*, 163: 106131. <https://doi.org/10.1016/j.ssci.2023.106131>
- [13] Yang, Y.P., Sun, Y., Chen, M.S., Zhou, Y.K., Wang, R., Liu, Z.X. (2022). Platform development of BIM-based fire safety management system considering the construction site. *Buildings*, 12(8): 1268. <https://doi.org/10.3390/buildings12081268>
- [14] Tyas, I.W., Munawir, A., Zaika, Y., Yusainy, C.,

- Widjaksono, E.T. (2026). Psychosocial safety climate as a mediator between safety culture and perceived safety performance in East Java mid-rise construction projects. *International Journal of Safety and Security Engineering*, 16(5): 1157-1168. <https://doi.org/10.18280/ijssse.160520>
- [15] Briones-Bitar, J., Pacheco-Bautista, L., Morante-Carballo, F., Berrezueta, E., Carrión-Mero, P. (2025). A systematic review of occupational health and safety to prevent fall accidents in civil works. *International Journal of Safety and Security Engineering*, 15(4): 819-833. <https://doi.org/10.18280/ijssse.150418>
- [16] Adebisi, R.T., Babalola, O., Amuda-Yusuf, G., Rasheed, S.A., Olowa, T.O. (2020). Effect of knowledge and compliance of health and safety information on construction sites workers' safety in Nigeria. *International Journal of Safety and Security Engineering*, 10(2): 269-277. <https://doi.org/10.18280/ijssse.100215>
- [17] Liu, J.J., Luo, H.B., Liu, H. (2022). Deep learning-based data analytics for safety in construction. *Automation in Construction*, 140: 104302. <https://doi.org/10.1016/j.autcon.2022.104302>
- [18] Tong, H., Li, X.Y., Shi, A., Xu, N., Guo, J. (2025). Knowledge support for emergency response during construction safety accidents. *Applied Sciences*, 15(21): 11760. <https://doi.org/10.3390/app152111760>
- [19] Maali, O., Ko, C.H., Nguyen, P.H.D. (2024). Applications of existing and emerging construction safety technologies. *Automation in Construction*, 158: 105231. <https://doi.org/10.1016/j.autcon.2023.105231>
- [20] Aktayeva, L., Bekmagambetov, A., Yedilbayeva, L., et al. (2025). Impact of green jobs on worker classification and categorization. *International Journal of Safety and Security Engineering*, 15(9): 1861-1872. <https://doi.org/10.18280/ijssse.150910>
- [21] Order of the Ministry of Labour and Social Protection of the Population of the Republic of Kazakhstan. (2020). On approval of the rules for occupational risk management. <https://adilet.zan.kz/rus/docs/V2000021197>.
- [22] Abikenova, S., Daumova, G., Kurmanbayeva, A., Yesbenbetova, Z., Kazbekova, D. (2022). Relationship between occupational risk and personal protective equipment on the example of ferroalloy production. *International Journal of Safety and Security Engineering*, 12(5): 609-614. <https://doi.org/10.18280/ijssse.120509>
- [23] Izmerov, N.F., Bukhtiyarov, I.V., Denisov, E.I. (2016). Evaluation of occupational risks in the system of evidence-based medicine (in Russian). *Issues of School and University Medicine and Health*, 1: 14-20. http://schoolshealth.ru/docs/1-2016/Izmerov%20NF%20et%20all_1_2016.pdf.
- [24] Rothman, K.J., Greenland, S., Lash, T.L. (2008). *Modern Epidemiology*, 3rd ed. Lippincott Williams & Wilkins, Philadelphia, PA.
- [25] Boadu, E.F., Okeke, S.R., Boadi, C., Osei Bonsu, E., Addo, I.Y. (2023). Work-related respiratory health conditions among construction workers: A systematic narrative review. *BMJ Open Respiratory Research*, 10(1): e001736. <https://doi.org/10.1136/bmjresp-2023-001736>
- [26] Tavakol, E., Azari, M., Zendehdel, R., et al. (2017). Risk evaluation of construction workers' exposure to silica dust and the possible lung function impairments. *Tanaffos*, 16(4): 295-303. <https://pubmed.ncbi.nlm.nih.gov/29849687/>.
- [27] Abikenova, S., Issamadiyeva, G., Kulmagambetova, E., Daumova, G., Abdrakhmanova, N. (2023). Assessing occupational risk: A classification of harmful factors in the production environment and labor process. *International Journal of Safety and Security Engineering*, 13(5): 871-881. <https://doi.org/10.18280/ijssse.130511>
- [28] Order of the Ministry of Labour and Social Protection of the Population of the Republic of Kazakhstan. (2022). On approval of the occupational health and safety rules for work at height. <https://adilet.zan.kz/rus/docs/V2200027349>.
- [29] International Labour Organization. (2022). Safety and health in construction: ILO code of practice. Revised edition. Geneva: International Labour Office. <https://www.ilo.org/resource/other/safety-and-health-construction-revised-edition>.

APPENDIX

Table A1. Checklist for ensuring compliance with legislative safety requirements for work at height

No.	Technical Requirements: Equipment
1	<i>Availability of technical specifications for equipment and protective devices</i>
1.1	Are technical specifications available for ladders?
1.2	Are technical specifications available for scaffolds and working platforms?
1.3	Are technical specifications available for climbing spurs and climbing devices?
1.4	Are technical specifications available for the fall protection system?
1.5	Are technical specifications available for energy-absorbing lanyards?
1.6	Are technical specifications available for mobile elevating work platforms (MEWPs)?
1.7	Are technical specifications available for anchor points?
2	<i>Personal protective equipment (PPE) and fall protection equipment</i>
2.1	Are workers provided with appropriate personal protective equipment (PPE)?
2.2	Are full-body harnesses free from damage, properly labeled, assigned an identification number, and within their service life?
3	<i>Completeness and serviceability of fall protection systems</i>
3.1	Are fall protection systems equipped with energy-absorbing lanyards to ensure continuous attachment?
3.2	Has the required fall clearance been correctly calculated, taking into account the full deployment length of the energy absorber and the worker's height?
4	<i>Anchor and attachment systems</i>
4.1	Is continuous attachment to anchor points maintained while working at height?
4.2	Where practicable, are reliable anchor points positioned above the worker's head level?

5	<i>Condition and proper use of fall protection equipment</i>
5.1	Are connectors, self-retracting lifelines, rope grabs, and other fall protection components free from damage and wear and maintained in good working condition?
5.2	Are full-body harnesses used in accordance with the manufacturer's instructions?
6	<i>High-risk activities (hot work)</i>
6.1	Are fire-resistant safety lanyards used during hot work?
7	<i>Collective protection and worksite organization</i>
7.1	Are workers provided with safety helmets with chin straps properly fastened?
7.2	Are safe procedures established for lowering and lifting tools and materials?
7.3	Have measures been implemented to prevent falling objects (tool lanyards, tool bags, retention devices)?
7.4	Are hazardous areas beneath the work zone designated, barricaded, and clearly marked?
8	<i>Mobile Elevating Work Platforms (MEWPs)</i>
8.1	Is the MEWP in safe operating condition, free from visible defects, and fully equipped?
8.2	Is the MEWP positioned on a stable and safe surface?
8.3	Does the operator hold valid qualifications, have appropriate training, and successfully completed competency assessment and safety induction?
	<i>Organizational and Management Requirements</i>
2	<i>Documentation and governing procedures</i>
2.1	Is there a corporate standard, work-at-height procedures, and a training program for work at height?
2.2	Has a work permit and risk assessment system been established and implemented in accordance with Order No. 344 of the Ministry of Labour and Social Protection of the Republic of Kazakhstan (28 August 2020)?
2.3	Have the company's Method Statement (MS) and standardized MS templates been developed?
2.4	Are the corporate standard and training program reviewed and updated annually?
2.5	Are lessons learned from fall-related incidents incorporated into the corporate standard and training programs?
2.6	Have specific control measures been developed for each identified fall hazard?
2.7	Has an inventory of fall protection systems been completed?
2.8	Have inspection records, rope-use logs, and PPE identification and labeling forms been developed?
2.9	Have procedures been established for the use of ladders, scaffolds, climbing spurs, climbing devices, mobile elevating work platforms (MEWPs), and fall protection systems?
2.10	Have emergency response plans been developed?
3	<i>Personnel</i>
3.1	Has a competent person been appointed to manage the inventory and inspect the serviceability of rope access equipment and personal fall protection systems?
3.2	Have specialists responsible for visual inspection of equipment been trained and certified?
3.3	Are records maintained for the certification and recertification of employees performing work at height?
3.4	Have all contractors been informed of and trained in the corporate standard and work-at-height training program?

Table A2. Dynamic risk assessment checklist for ensuring compliance with legislative safety requirements for outdoor work

No.	Checklist for Assessing Site Readiness for Safe Operations under Adverse Climatic Conditions
1	Has the operational condition of lifting equipment (aerial work platforms, cranes, suspended platforms) been verified, taking into account operating authorization and prevailing weather conditions (wind, rain, ice)?
2	Have scaffolds, working platforms, walkways, and guardrails been inspected to ensure the absence of damage, excessive movement, instability, or slip hazards caused by high humidity or icing?
3	Are all fall protection systems (full-body harnesses, lifelines, ropes, and connectors) in good working condition, and have they undergone visual inspection and verification of attachment integrity?
4	Is all equipment and tooling (including ladders, welding and installation equipment, ropes, rigging equipment, and accessories) in serviceable condition and suitable for operation under temperature fluctuations, rain, dust, and high humidity?
5	Have welding machines and gas cylinder installations undergone technical inspection, and have any gas leaks associated with pressure changes caused by temperature fluctuations been ruled out?
6	Are ventilation and exhaust systems operating effectively, particularly in areas where welding, gas-related, or excavation work is performed under conditions of high temperature, stagnant air, or insufficient ventilation?
7	Does the technical condition of drilling rigs, vehicles, and construction equipment comply with the requirements for outdoor operation, including stability on soft or water-saturated ground?
8	Are quarry walls, benches, and slopes stable, compliant with the design geometry, and free from signs of erosion, collapse, or washout following precipitation?
9	Are work areas, storage areas, spoil heaps, and berms level, free from erosion, wheel ruts, standing water, cracks, or deterioration caused by water or prolonged solar exposure?
10	Is the road surface used by construction vehicles capable of withstanding traffic loads under high temperatures or excessive moisture, is the drainage system functioning properly, and has water accumulation been prevented?
11	Are first-aid kits, radios/mobile phones, protective screens, warning tapes, traffic signs, reflectors, and dust suppression equipment available and in proper working condition?
12	Are clearly visible barriers and warning signs installed in work areas adjacent to roads and traffic routes?
13	Have weather conditions been taken into account when positioning equipment and warning signs (protection against wind, rain, and overheating of equipment)?
	Has each employee been provided with personal protective equipment (PPE) appropriate for the assigned tasks and prevailing weather conditions, including:
14	• for hot weather - lightweight protective clothing, sun protection, and cooling vests; • for rainy conditions - waterproof clothing and slip-resistant footwear; • for cold weather - insulated clothing, gloves, and head protection;

-
- for dusty environments - appropriate respiratory protective equipment (RPE)?
- 15 Has a visual inspection of PPE been conducted before work to ensure the absence of damage, wear, or loss of protective properties, particularly after storage under hot, cold, or humid conditions?
- 16 Is approved project documentation available, and has compliance of the planned work with the design documentation and site conditions been verified?
- 17 Has a work execution plan been developed and approved, including resource allocation and assignment of responsible personnel?
- 18 Has a risk assessment been conducted considering weather-related factors (high or low temperatures, precipitation, humidity, visibility, icing, etc.), and has an action plan been prepared to mitigate microclimatic and environmental hazards?
- 19 Has the need to adjust the work schedule under adverse weather conditions (wind speeds >15 m/s, thunderstorms, temperatures above 30°C, temperatures below -15°C, etc.) been taken into account?
- 20 Have induction, job-specific, and task-specific occupational health and safety briefings been conducted, including instructions on the specific hazards associated with outdoor work (e.g., heat exposure, slippery surfaces, reduced visibility, etc.)?
- 21 Are all employees provided with appropriate personal protective equipment (PPE) adapted to the current weather conditions (summer and winter protective clothing, protection against precipitation, wind, solar radiation, dust, and moisture)?
- 22 Have work permits been issued for high-risk activities (work at height, welding, excavation, drilling and blasting, etc.), taking into account weather-related restrictions (e.g., prohibition of work during thunderstorms, icy conditions, or high winds)?
- 23 Has workers' physical condition been assessed before authorizing them to begin work, particularly under conditions of heat, cold, or high humidity?
- 24 Are all hazardous areas (work at height, trenches, welding areas, and vehicle operating zones) clearly marked and barricaded, and are measures in place to prevent barriers from being displaced by wind or damaged by precipitation?
- 25 Have safe routes for the movement of personnel and vehicles been established, taking into account terrain, slippery surfaces, drainage, and the potential for temporary flooding?
- 26 Are the required safety clearances maintained from overhead power lines, railway tracks, roads, and weather-sensitive facilities (e.g., storage tanks, gas cylinders, cable routes)?
- 27 Are safety signs and warning notices installed at the worksite, resistant to environmental conditions (wind, rain, and sunlight), and clearly visible under reduced lighting or foggy conditions?
- 28 Are shelters or temporary canopies provided to protect workers from direct exposure to adverse weather conditions (sun, snow, or rain)?
- 29 Is access provided to drinking water, heating/cooling stations, and first-aid equipment for the treatment of heat stress, hypothermia, or other weather-related health conditions?
- 30 Have equipment and lifting devices undergone technical inspection, and has their operational safety under current weather conditions (wind, rain, icing, or high temperatures) been verified?
- 31 Have temporary construction structures (scaffolds, working platforms, and walkways) been inspected for damage, excessive movement, corrosion, slip hazards, and signs of instability under conditions of high humidity or wind loading?
- 32 Are fall protection systems (full-body harnesses, connectors, lifelines, and anchor lines) in proper working condition, and have they been verified for reliable operation under low or high temperatures, dusty conditions, and moisture?
- Has the operational readiness and serviceability of the following been verified:
- 33 • ventilation systems (particularly in enclosed or below-ground work areas where heat or hazardous gases may accumulate);
 - firefighting equipment (taking storage temperature requirements into account);
 - first-aid equipment, including supplies for the treatment of heat stress, hypothermia, and burns?
- Have the following been inspected:
- 34 • road surfaces (for resistance to rutting, slipping, washout after precipitation, and overheating due to solar exposure);
 - drainage systems (for proper operation and the absence of blockages or flooding);
 - berms, slopes, and spoil heaps (for stability and the absence of erosion, washouts, landslides, or frost-related damage)?
- 35 Are personnel prohibited from entering blasting areas without an approved work permit and unless appropriate barriers, warning signs, and visual supervision are in place?
- 36 Are unauthorized persons excluded from loading areas and other hazardous work zones, particularly during fog, dust, rain, or reduced visibility?
- 37 Have all workers been informed about hazardous areas, including trenches, excavations, cliffs, and slopes, particularly under conditions of precipitation, frozen ground, or increased risk of collapse?
- 38 Are the boundaries of work areas, ore storage zones, bench edges, spoil heaps, and traffic routes clearly marked and communicated to personnel, taking into account changes in visibility caused by microclimatic conditions?
- 39 Do personnel follow the designated traffic routes within the worksite and avoid taking shortcuts through hazardous areas?
- 40 Have all workers been informed of vehicle speed limits, particularly under conditions of reduced surface traction caused by mud, ice, standing water, or steep gradients?
- 41 Do workers correctly recognize and understand the meaning of visual safety devices, including safety signs, warning tapes, traffic cones, and information boards, even under reduced lighting or dusty conditions?
- 42 Are personal belongings, tools, cables, and equipment kept clear of walkways and emergency evacuation routes, particularly under conditions of reduced visibility, night work, or slippery surfaces?
- 43 Are vehicles parked in designated safe areas without obstructing the movement of personnel or construction equipment, and are they located outside areas at risk of flooding, collapse, or unstable slopes?
- 44 Have workers received both task-specific safety instructions and additional briefings addressing the specific weather conditions expected during the work (e.g., heat, fog, wind, precipitation, dust, or frost)?
-

Table A3. Source data and calculations of relative risk (RR) and etiologic fraction (EF) for pilot enterprise No. 1

Group / Indicator	Total Number of Workers	Workers with Recorded Morbidity	Injuries	Upper Respiratory Tract Diseases	Hearing Impairment	Cardiovascular Diseases	Visual Disorder	Gastrointestinal Diseases	Urinary System Diseases	Skin Disease	Musculoskeletal Disorders
Control group	37	11	0	2	1	2	3	1	0	1	1
Exposed group	225	86	17	27	10	0	0	7	2	9	14
Relative risk (RR)				2.22	1.64			1.15		1.48	2.30
Etiologic fraction (EF), %				54.95%	39.02%			13.04%		32.43%	56.52%
Degree of association				High	Moderate			Low		Low	High

Note: The table presents the numbers of workers in the exposed and control groups and the disease-specific case counts used to calculate RR and EF. These data allow verification and reproduction of the estimates presented in Table 5.

Calculations for Pilot Enterprise No. 1:

Upper respiratory tract diseases:

$$RR = (27/225) / (2/37) = 2.22$$

$$EF = (2.22 - 1) / 2.22 \times 100\% = 54.95\%$$

Hearing impairment:

$$RR = (10/225) / (1/37) = 1.64$$

$$EF = (1.64 - 1) / 1.64 \times 100\% = 39.02\%$$

Gastrointestinal diseases:

$$RR = (7/225) / (1/37) = 1.15$$

$$EF = (1.15 - 1) / 1.15 \times 100\% = 13.04\%$$

Skin diseases:

$$RR = (9/225) / (1/37) = 1.48$$

$$EF = (1.48 - 1) / 1.48 \times 100\% = 32.43\%$$

Musculoskeletal disorders:

$$RR = (14/225) / (1/37) = 2.30$$

$$EF = (2.30 - 1) / 2.30 \times 100\% = 56.52\%$$

Table A4. Source data and calculations of relative risk (RR) and etiologic fraction (EF) for pilot enterprise No. 2

Group / Indicator	Total Number of Workers	Workers with Recorded Morbidity	Injuries	Upper Respiratory Tract Diseases	Hearing Impairment	Cardiovascular Diseases	Visual Disorder	Gastrointestinal Diseases	Musculoskeletal Disorders
Control group	25	5	0	1	1	0	1	1	1
Exposed group	108	90	17	20	17	2	18	0	17
Relative risk (RR)				4.63	3.94		4.17		3.94
Etiologic fraction (EF), %				78.40%	74.62%		76.02%		74.62%
Degree of association				Very high	Very high		Very high		Very high

Note: The table presents the numbers of workers in the exposed and control groups and the disease-specific case counts used to calculate RR and EF. These data allow verification and reproduction of the estimates presented in Table 5.

Calculations for Pilot Enterprise No. 2:

Upper respiratory tract diseases:

$$RR = (20/108) / (1/25) = 4.63$$

$$EF = (4.63 - 1) / 4.63 \times 100\% = 78.40\%$$

Hearing impairment:

$$RR = (17/108) / (1/25) = 3.94$$

$$EF = (3.94 - 1) / 3.94 \times 100\% = 74.62\%$$

Visual disorders:

$$RR = (18/108) / (1/25) = 4.17$$

$$EF = (4.17 - 1) / 4.17 \times 100\% = 76.02\%$$

Musculoskeletal disorders:

$$RR = (17/108) / (1/25) = 3.94$$

$$EF = (3.94 - 1) / 3.94 \times 100\% = 74.62\%$$