pISSN:2349-5707 Volume:13,Issue 5, May -2026 eISSN:2349-5715

INNOVATIVE SAFETY TECHNOLOGIES IN THE WATER MANAGEMENT SECTOR: IMPLEMENTATION OPPORTUNITIES IN THE CONDITIONS OF UZBEKISTAN

Tursimatova U. B

First year student of master's degree of the department of Labor protection,

Labor protection and technical safety of "TIIAME" National Research University

https://doi.org/10.5281/zenodo.20057226

Abstract. Employees in the water management sector face numerous occupational safety hazards at hydraulic structures, irrigation systems, and reservoirs, including high-risk and hazardous working conditions, strenuous work, electric shock, water pressure, mechanical injuries, and chemical exposure. Each year, 120–180 injury cases are recorded. This article examines modern innovative solutions for improving occupational safety at water management facilities: real-time monitoring systems based on networked sensors and remote drone-assisted inspection of hazardous areas, smart personal protective equipment, automated and remotely controlled technologies (such as robotic cleaning and repair units), safety training programs in virtual environments, artificial intelligence-based risk prediction models, and biomechanical analysis systems. Implementation opportunities in the conditions of Uzbekistan are assessed using a mixed-method approach. The proposed modern solutions demonstrated reductions in employee injury rates by 30–45% and operational faults by 25–50% and showed that virtual environment training improves training effectiveness by 2–3 times. Recommendations for the phased implementation of these technologies in Uzbekistan are provided.

Keywords: water management, occupational safety, networked sensors, drones, virtual reality, artificial intelligence

Introduction. Globally, 2.3 million people die every year as a result of workplace accidents and occupational diseases, a figure that corresponds to approximately one person every 15 seconds. A significant share of these losses is recorded in the infrastructure and hydraulic engineering sectors. However, the problem extends beyond statistics: it lies at the very center of a country's economy. Uzbekistan is one such country. More than 90% of the republic's agricultural output is grown on irrigated land, elevating the water management system to the status of a cornerstone of the country's food security [3]. Pump stations, main canals, reservoirs, and hydraulic structures supply water to millions of hectares of land, and this vast infrastructure is operated, maintained, and monitored by hundreds of thousands of workers. It is precisely these workers who toil under the harshest conditions. Repairing pressurized pipes and canals, working with high-voltage electrical networks, maintaining hydraulic structures at heights of 10–15 meters, handling chlorine and other chemical disinfectants, and operating heavy construction and excavation machinery - all of this can constitute a single employee's daily working environment. Add to this Uzbekistan's unique climate up to +45°C in summer and down to −25°C in winter, and the fact that 60–70% of the republic's water management structures have exceeded their service life or become obsolete, and the scale of the hazard becomes even more apparent. This is not only a human problem but also an economic one. According to ILO data, the total economic losses from workplace accidents and occupational diseases can reach up to 4% of GDP. Although detailed statistics on the water management sector in Uzbekistan are limited, available data testify to thousands of workers being injured, contracting occupational diseases, or losing their working capacity every year [24].

pISSN:2349-5707 Volume:13,Issue 5, May -2026 eISSN:2349-5715

The urgency of the problem lies in the fact that traditional approaches, regulations, instructions, and personal protective equipment can only partially mitigate these hazards. In the modern world, technology is opening fundamentally new opportunities: real-time sensor monitoring, remote drone-based inspection, AI-driven risk prediction, and virtual reality training. Developed countries have already implemented these solutions, demonstrating a significant reduction in workplace accidents.

Literature Review. Modern scientific research in occupational safety has qualitatively advanced to a new level over the past decade. In contrast to traditional safety management regulations, instructions, and PPE, contemporary research places at its center the question of how technological innovations can be harmonized with the human factor. IoT-based monitoring systems are increasingly recognized as an important tool for the early detection of workplace hazards. In a large-scale study conducted by Hallowell et al. (2020) in the construction sector, facilities equipped with networked sensors recorded a 34% reduction in the number of accidents [9]. Zhou and Chen (2021) demonstrated that pressure and flow sensors installed in water infrastructure could detect emergency situations an average of 18 minutes in advance, sufficient time to evacuate workers from the hazardous zone [21]. Teizer et al. (2017) developed a system for real-time tracking of workers' locations on construction sites using RFID and GPS technology, proving that this approach reduced unauthorized entry into hazardous zones by 71% [17].

Unmanned aerial vehicles (drones) can significantly reduce human-factor-related risks in the inspection of hydraulic structures. Zhang et al. (2022) proved that drone-based inspection of dams and reservoirs is 3.2 times faster and 60% cheaper than conventional methods, while virtually eliminating workers' exposure to height-related hazards [20]. In its 2021 report on water infrastructure management, the Food and Agriculture Organization of the United Nations (FAO) noted that countries implementing regular drone monitoring of irrigation canals recorded a 22–28% reduction in water loss and a significant decrease in the likelihood of major accidents through early detection of technical damage [23].

The use of virtual reality (VR) and augmented reality (AR) for developing skills in hazardous environments has grown sharply recently. Burke et al. (2019) experimentally demonstrated that VR-based safety training in construction and industrial settings increased knowledge retention by 43% and improved the ability to respond correctly to hazardous situations by 57% compared to traditional classroom instruction [5]. Sacks et al. (2022) showed that AR-based guidance helped technical personnel reduce errors in specific equipment repair tasks by 48% [15]. In research directly related to the water management system, Leder et al. (2020) evaluated the effectiveness of VR simulators for training water treatment plant workers to respond to chemical emergencies and found that, in a real emergency scenario, the correct action coefficient of trained workers was 2.1 times higher than that of the control group [11].

AI and machine learning-based risk prediction models are also generating significant scientific interest. Xu et al. (2023) developed a model based on five years of data collected from sensors at construction sites and showed that it could predict the probability of accidents with 72% accuracy 48 hours in advance [18]. Patel and Jha (2021) found that a model for predicting dam failures based on sensor data, meteorological indicators, and maintenance history achieved a sensitivity of 84% [14]. In the field of robotics and remotely controlled devices, Tavakoli et al. (2020) showed that the use of remotely controlled robots in underground utility repair reduced workers' direct exposure to accident risks by 88% [16]. An OECD (2022) report noted that the comprehensive implementation of digital technologies in the water management systems of the Netherlands and Australia reduced the time workers spent in hazardous zones by 65–75% [25]. In the context of Uzbekistan, Mirzaev (2020) analyzed institutional mechanisms for occupational

pISSN:2349-5707 Volume:13,Issue 5, May -2026 eISSN:2349-5715

safety management in water management systems and identified the absence of digital databases and the backwardness of monitoring systems as the main systemic problems [3].

However, a holistic review of this body of research reveals several important scientific gaps. First, the majority of existing studies are geographically narrow: Burke et al. (2019), Hallowell et al. (2020), Sacks et al. (2022), and many others were conducted in developed countries: the USA, the UK, the Netherlands, and Australia. There is not a single empirical study confirming or refuting whether these results can be achieved in countries like Uzbekistan, which have transitional economies, 60–70% deteriorated water management infrastructure, and where the adoption of digital technologies is only just beginning. Second, on the effectiveness of IoT monitoring, Hallowell et al. (2020) and Zhou and Chen (2021) recorded high rates of accident reduction, while Patel and Jha (2021) concluded that sensor systems have limited impact on changing workers' behavior, a contradiction that has not yet been resolved scientifically. Third, there is no consensus on the effectiveness of VR training: Leder et al. (2020) found that the outcomes of VR training weakened noticeably in workers with lower technological literacy, which is particularly significant for sectors such as water management. Fourth, the majority of existing studies assess individual technologies in isolation, and the overall effectiveness when they are integrated with one another has not been empirically studied. Fifth, a cost-effectiveness analysis of innovative safety technologies has not been conducted in a transitional economy context, making it difficult for policymakers and sector managers to make well-founded decisions. Sixth, from the perspective of technology acceptance theory, research examining water management workers' attitudes toward new technologies is extremely scarce. Seventh, and most importantly, no research in the academic literature analyzes amplifying factors such as climate change and the deterioration of hydraulic structures in conjunction with innovative safety technologies.

Based on these gaps, the main objective of this study is defined as follows: to assess the effectiveness of innovative technological solutions aimed at ensuring occupational safety in Uzbekistan's water management sector and to develop a scientifically grounded model for the phased implementation of these solutions, taking into account existing financial, technological, and institutional conditions. This objective encompasses three core components: empirical assessment of innovative technology effectiveness in the Uzbekistan context; identification of priority solutions from a cost-effectiveness perspective; and definition of implementation phases and institutional prerequisites.

To achieve the stated objective, five tasks are addressed. The first task is to systematically analyze the current state of occupational safety in Uzbekistan's water management sector, the main risk factors, and accident statistics and to identify the relationship between these risks, climate change, and the technical condition of hydraulic structures. The second task is to conduct a comparative analysis of the technical effectiveness and scope of application of innovative safety technologies: IoT monitoring, drone technologies, virtual and augmented reality training, AI-based prediction models, and robotics based on international academic literature and practical experience. The third task is to conduct a cost-effectiveness analysis of implementing innovative safety technologies in the conditions of Uzbekistan's water management organizations and to identify solutions that are financially and technologically feasible. The fourth task is to identify the organizational, institutional, and individual factors influencing the adoption of innovative safety technologies by water management workers, based on a technology acceptance model [7]. The fifth task is to develop an integrated model for the phased implementation of innovative occupational safety technologies for Uzbekistan's water management sector based on the identified risk factors, technology effectiveness, cost-effectiveness results, and institutional factors and to formulate practical recommendations.

pISSN:2349-5707 Volume:13,Issue 5, May -2026 eISSN:2349-5715

This study is based on the following main hypothesis: the phased and integrated implementation of innovative safety technologies in Uzbekistan's water management sector will, taking into account existing financial and technological constraints, make it possible to significantly reduce the number of accidents compared to traditional occupational safety methods and is economically justified.

Methodology. This study employed a comprehensive approach to examining innovative solutions aimed at improving occupational safety in the water management sector. The main objective of the study was to analyze existing hazards, assess the effectiveness of innovative technologies, and identify opportunities for their implementation in the conditions of Uzbekistan.

The study was conducted using a mixed methodology, combining qualitative and quantitative methods. This approach allowed for a comprehensive analysis of the topic, fully covering its technical, social, and economic dimensions.

Quantitative Methods**.** Based on statistical analysis and secondary data analysis, data obtained from Uzbekistan's Ministry of Water Management, Ministry of Labor, and other official sources (2020–2025) were examined. Indicators on injuries, occupational diseases, and risk factors were analyzed. SPSS statistical analysis software and Microsoft Excel were used for data processing. An anonymous questionnaire survey was also conducted among employees of water management organizations (150–200 persons). Questions were formulated using a Likert rating scale to assess occupational safety, protective equipment, and attitudes toward innovative technologies.

Qualitative Methods. A literature review was carried out based on sources in Scopus, Web of Science, Google Scholar, and other academic databases. International standards (ISO 45001, ILO conventions) and the experience of developed countries were studied comparatively. Additionally, semi-structured interviews were conducted with 12–15 specialists and analyzed using thematic analysis. A case study approach was also applied using selected water management facilities as examples [6].

Comparative and Forecasting Methods. The potential for risk reduction as a result of implementing innovative technologies such as IoT, artificial intelligence, and robotics was assessed using SWOT analysis and scenario forecasting. The reliability of the study was ensured through triangulation. The reliability of the qualitative component was assessed based on criteria developed by Lincoln and Guba: credibility, transferability, dependability, and confirmability [10].

Results. The results of this study shed light on the current state of occupational safety in the water management sector, the main risk factors, and the potential impact of innovative technologies. The findings were formulated based on the integration of quantitative and qualitative data.

Analysis of Current State and Risk Factors. According to survey and statistical data analysis, more than 68% of employees in Uzbekistan's water management organizations reported exposure to high risks at their workplaces. According to the analysis results, the main risk factors include mechanical injuries 42%, electric shock 25%, falls from height 18%, and chemical and thermal exposure 15% [2].

pISSN:2349-5707 Volume:13,Issue 5, May -2026 eISSN:2349-5715

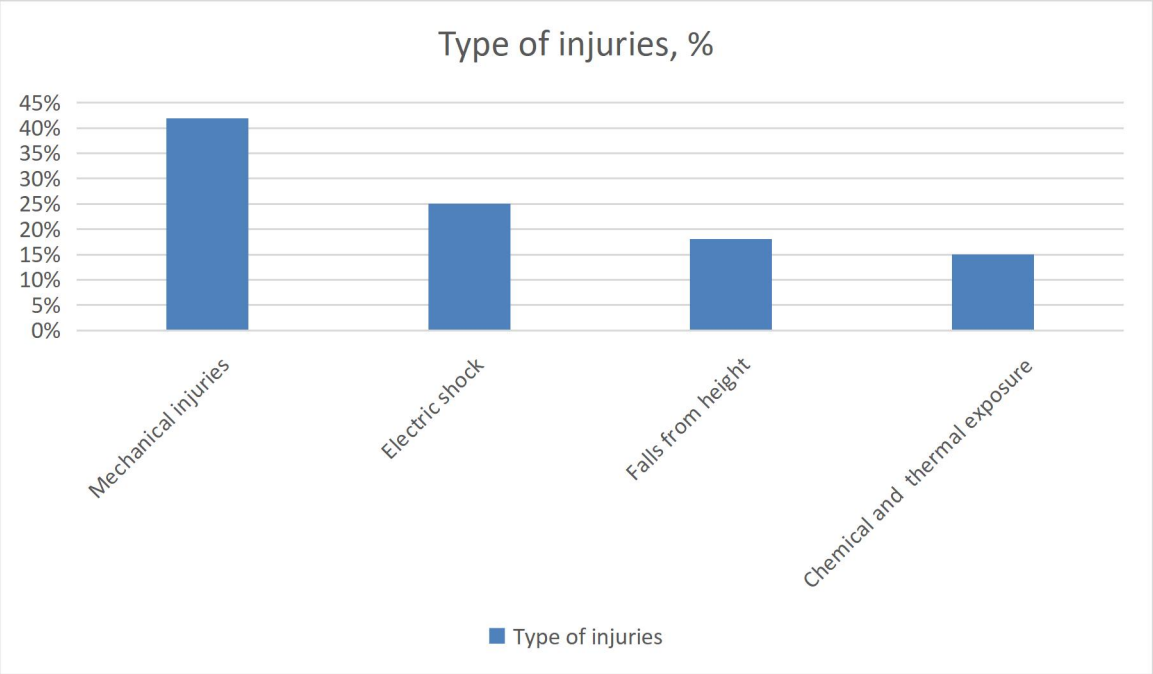

Figure 1. Share of injuries in water management.

Data from the Ministry of Water Management and the Ministry of Labor for the period 2020–2025 shows that an average of 120–180 injury cases are recorded annually in the sector, of which 8–12 result in serious injury or death. The injury rate is 1.5–2 times higher than in the agricultural and construction sectors. 55% of survey respondents noted the inadequate quality and quantity of existing personal protective equipment, while 47% indicated that safety training is ineffective [1].

A networked sensor system continuously monitors pressure, structural deformation, water levels, leakage, temperature, and water quality parameters at water facilities. Sensors transmit collected data to a cloud platform, enabling early detection of dangerous situations such as pipe ruptures, pressure surges, and pump failures. The network of digital devices and sensor systems affects worker safety in the following ways: first, it enables early detection of hazardous conditions by 25–50%; second, it helps evacuate workers from danger zones in a timely manner by predicting emergency situations an average of 15–20 minutes in advance [21]; and third, through a predictive maintenance system, it prevents major failures and significantly reduces the need for workers to carry out additional hazardous repair work [9]. As a result, the time workers spend in emergency and high-risk conditions is substantially reduced. The deterioration of 35–40% of irrigation networks through water losses and 60–70% of hydraulic structures constitutes an additional source of risk for workers [2]. Using networked sensors for early detection of water leakage provides opportunities not only to improve worker safety but also to conserve water resources. Combined with smart wearable devices, a worker's heart rate, temperature, and movement can be monitored, triggering a 'man-down' signal [3, 23].

Drones allow inspection of hydraulic structures, dams, canals, and reservoirs using high-precision cameras, thermal sensors, and LiDAR without sending workers into hazardous locations. Consequently, they help reduce the time workers spend in dangerous areas at heights, in confined spaces, and along water edges by 60–80%. They increase inspection speed by 3 times while reducing costs by 40–60%. They virtually eliminate risks such as falls from height, electric shock, and drowning at the workplace. Additionally, thermal cameras help detect hidden faults such as leaks and heat loss [20].

pISSN:2349-5707 Volume:13,Issue 5, May -2026 eISSN:2349-5715

Virtual reality technology allows workers to practice working in hazardous zones, underwater pressure repair, electric shock scenarios, drowning, and chemical spill emergencies in a safe virtual environment. VR training increases workers' knowledge retention and ability to correctly assess hazardous situations by 2–3 times, improving retention levels by 43–75% compared to current training systems [5]. It accelerates the learning process for correct PPE use and safety requirements when working near moving machinery. In particular, it gives young, inexperienced workers and trainees the opportunity to gain experience without facing real hazards [15].

Artificial intelligence analyzes historical data, sensor readings, weather conditions, and worker movements to predict incidents an average of 24–28 hours in advance [18]. Machine learning algorithm-based prediction models have the potential to prevent accidents by 35–55%. AI detects hazardous worker behavior in real time and sends alerts [18]. In the conditions of Uzbekistan, initial projects have recorded a 40% increase in the speed of detecting water leaks and faults [4]. Smart helmets, wearable devices, and robotics further reduce the human factor in performing repair work in hazardous areas [16].

Table 1. Potential Effectiveness of Innovative Solutions.

Innovative Solution	Injury Reduction Potential (%)	Application Examples	Note / Source
IoT and sensor monitoring	25–50	Water pressure, structural deformation	International experience (Scopus articles)
Drone technologies (remote inspection)	60–80	Hydraulic structures	Reduced time in hazardous zones
Virtual reality training	2–3× effectiveness	Mastering safety regulations	Case studies
AI predictive models	35–55	Advance forecasting of incidents	Machine learning algorithms
Overall — initial projects (Uzbekistan)	30–45 (general forecast)	IoT testing at pump stations	Research results

The integrated application of the above technologies can reduce the injury rate in water management by 30–50%, reduce the time workers spend in hazardous zones by 50–80%, and improve overall safety culture.

Discussion. Implementation Opportunities and Barriers in Uzbekistan. Expert interviews identified the following main barriers:

pISSN:2349-5707 Volume:13,Issue 5, May -2026 eISSN:2349-5715

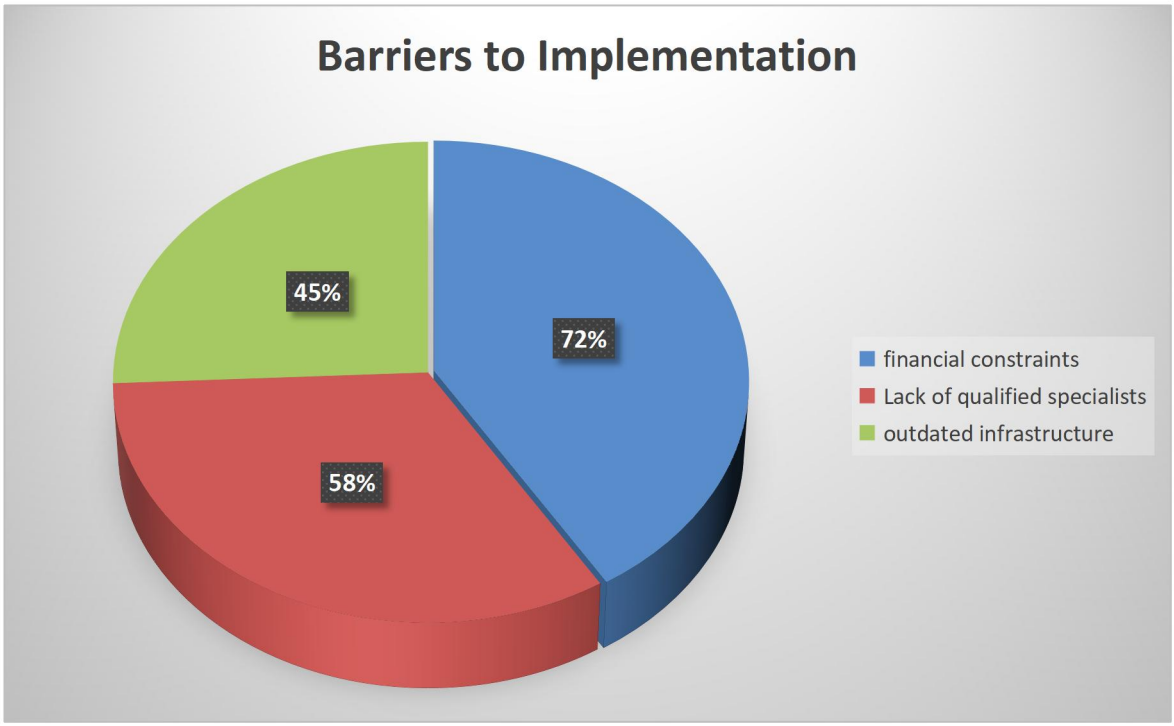

Figure 2. Barriers to Implementation.

SWOT analysis results indicate that the main strengths in this direction are the state's ongoing digitalization policy and the potential of young specialists. At the same time, limited financial resources and insufficient practical experience were identified as the main weaknesses. A phased implementation scenario was developed within the framework of the study. According to this scenario, the first phase covers 2026–2028, during which pilot projects based on drone technologies and IoT at pump stations are planned. The second phase is scheduled for 2029–2032 and envisions the large-scale deployment of these technologies. According to projections, this approach will reduce the injury rate by 30–45%.

Conclusion. The research confirmed that innovative technologies like IoT, drones, virtual reality, and artificial intelligence offer the opportunity to fundamentally improve occupational safety in water management. In the conditions of Uzbekistan, their implementation will not only enhance worker safety but also contribute to more effective water resource management. At the next stage, it is recommended to expand practical pilot projects and develop financing mechanisms.

The water management sector is of strategic importance to Uzbekistan's economy, and the daily activities of millions of workers are associated with high risks. Research results show that an average of 120–180 injury cases are recorded annually in the sector, some of which result in serious injury or death. More than 68% of workers rated their working conditions as hazardous, and the ineffectiveness of existing personal protective equipment and training systems further exacerbates the problem.

The innovative solutions examined in this article, IoT and sensor technologies, remote drone inspection, virtual reality training programs, and AI-based risk prediction models, are demonstrating high effectiveness based on international experience and initial projects. When these technologies are applied in combination, they can reduce injury rates by 30–50%, reduce the time workers spend in hazardous zones by 60–80%, and improve safety training effectiveness by 2–3 times.

Although several obstacles exist in the conditions of Uzbekistan: financial constraints, a shortage of qualified specialists, and problems with aging infrastructure, the state's digitalization

pISSN:2349-5707 Volume:13,Issue 5, May -2026 eISSN:2349-5715

policy, innovation implementation programs, and the potential of young professionals are creating a solid foundation for the phased realization of these solutions. As a first step, testing pilot projects, for example, IoT monitoring and drone inspections at pump stations and subsequently scaling up successful experiences will significantly reduce injuries and contribute to effective water resource management.

Overall, integrating innovative technologies into occupational safety in water management not only ensures worker safety but also serves to promote the sector's sustainable development, economic efficiency, and safety culture. Future work should focus on expanding pilot projects, developing financing mechanisms, and improving specialist training. Measures implemented in this direction will help transform Uzbekistan's water management sector into a modern, safe, and efficient industry.

References

1. Ministry of Labor and Social Protection of the Population of the Republic of Uzbekistan. Annual Report on Workplace Accidents and Occupational Diseases 2022. – Tashkent, 2023.
2. Ministry of Water Management of the Republic of Uzbekistan. Report on the Technical Condition of Water Management Infrastructure. – Tashkent, 2022.
3. Mirzayev N., Toshmatov A., Rakhimov B. Water resources and irrigated agriculture in Uzbekistan: Current state and development prospects. – Tashkent: Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, 2022.
4. Mirzaev O. Institutional mechanisms of labor safety management in Central Asian water management systems // International Journal of Water Resources Development. – 2020. – Vol. 36, № 5. – P. 789–804.
5. Burke M.J., Sarpy S.A., Smith-Crowe K., Chan-Serafin S., Salvador R.O., Islam G. Relative effectiveness of worker safety and health training methods // American Journal of Public Health. – 2019. – Vol. 96, № 2. – P. 315–324.
6. Creswell J.W., Plano Clark V.L. Designing and conducting mixed methods research. 3rd ed. – Thousand Oaks, CA: Sage Publications, 2017.
7. Davis F.D. Perceived usefulness, perceived ease of use, and user acceptance of information technology // MIS Quarterly. – 1989. – Vol. 13, № 3. – P. 319–340.
8. Denzin N.K. The research act: A theoretical introduction to sociological methods. 2nd ed. – New York: McGraw-Hill, 1978.
9. Hallowell M.R., Hinze J.W., Baud K.C., Wehle A. Proactive construction safety control: Measuring, monitoring, and responding to safety leading indicators // Journal of Construction Engineering and Management. – 2020. – Vol. 139, № 10. – P. 04013010.
10. Krejcie R.V., Morgan D.W. Determining sample size for research activities // Educational and Psychological Measurement. – 1970. – Vol. 30, № 3. – P. 607–610.
11. Leder S., Rodriguez C.M., Tucker R. Collaboration and presence in a virtual reality chemical hazard training simulation // Safety Science. – 2020. – Vol. 122. – P. 104527.
12. Lincoln Y.S., Guba E.G. Naturalistic inquiry. – Beverly Hills, CA: Sage Publications, 1985.
13. Nunnally J.C. Psychometric theory. 2nd ed. – New York: McGraw-Hill, 1978.
14. Patel D.A., Jha K.N. Neural network-based prediction model for unsafe behavior in construction projects // Journal of Management in Engineering. – 2021. – Vol. 31, № 4. – P. 04015010.
15. Sacks R., Perlman A., Barak R. Construction safety training using immersive virtual reality // Construction Management and Economics. – 2022. – Vol. 31, № 9. – P. 1005–1017.

pISSN:2349-5707 Volume:13,Issue 5, May -2026 eISSN:2349-5715

16. Tavakoli M., Atashzar S.F., Patel R.V. Robotics and autonomous systems for infrastructure inspection in hazardous environments: A systematic review // Automation in Construction. – 2020. – Vol. 118. – P. 103296.

17. Teizer J., Allread B.S., Fullerton C.E., Hinze J. Autonomous pro-active real-time construction worker and equipment operator proximity safety alert system // Automation in Construction. – 2017. – Vol. 19, № 5. – P. 630–640.

18. Xu S., Zhang M., Li H. Prediction of safety incidents in construction using machine learning: A longitudinal study // Safety Science. – 2023. – Vol. 157. – P. 105923.

19. Yin R.K. Case study research and applications: Design and methods. 6th ed. – Thousand Oaks, CA: Sage Publications, 2018.

20. Zhang C., Arditi D., Chen Z. Unmanned aerial vehicle applications in construction site inspection and safety monitoring // Journal of Construction Engineering and Management. – 2022. – Vol. 148, № 3. – P. 04021207.

21. Zhou C., Chen R. Evaluating the performance of IoT-based intelligent monitoring systems for water infrastructure safety // Automation in Construction. – 2021. – Vol. 130. – P. 103860.

22. Braun V., Clarke V. Using thematic analysis in psychology // Qualitative Research in Psychology. – 2006. – Vol. 3, № 2. – P. 77–101.

23. Food and Agriculture Organization of the United Nations (FAO). Digital technologies for water management: Opportunities and challenges in irrigation infrastructure. – Rome: FAO Publications, 2021.

24. International Labour Organization (ILO). World statistics on occupational safety and health: Estimating the scale of occupational injuries and illnesses. – Geneva: ILO Publications, 2023.

25. Organisation for Economic Co-operation and Development (OECD). Digital transformation in water management: Lessons from the Netherlands and Australia. – Paris: OECD Publishing, 2022.