International Journal of Advances in Applied Sciences (IJAAS)
Vol. 15, No. 2, June 2026, pp. 555~572
ISSN: 2252-8814, DOI: 10.11591/ijaas.v15.i2.pp555-572

An integrated EHS-based risk assessment framework for hazardous substance storage: regulatory gap analysis in Thailand

Hengheng Jarunongkran, Therdpong Daengsi
Department of Sustainable Industrial Management Engineering, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Bangkok, Thailand

Article Info

Article history:

Received Jul 25, 2025
Revised Feb 25, 2026
Accepted Apr 22, 2026

Keywords:

ASEAN harmonization
DIW compliance
EHS-based risk assessment
Hazardous substance
Risk assessment

ABSTRACT

This study examines hazardous substance storage risk assessment within the environmental, health, and safety (EHS) framework, focusing on Thailand's regulatory context. Using a systematic review and comparative regulatory analysis, the research evaluates existing risk assessment methodologies and identifies structural and implementation gaps in current practices. The findings reveal deficiencies in the integration of toxicological data with legal requirements, fragmented regulatory enforcement, limited standardization, and insufficient practical tools for workplace application. A comparative assessment of international frameworks, including European Union Registration, Evaluation, Authorization, and Restriction of Chemicals (EU REACH), United States Occupational Safety and Health Administration (US OSHA), and Japan's Chemical Substances Control Law (CSCL), highlights best practices in proactive risk management and transparency. Based on these insights, the study proposes an integrated EHS-based risk assessment framework that aligns Department of Industrial Works (DIW) regulations with international standards such as ISO 14001, ISO 45001, and globally harmonized system (GHS). The proposed model supports proactive risk identification, regulatory coherence, and improved stakeholder awareness, contributing to enhanced chemical safety governance and ASEAN harmonization.

Corresponding Author:

Therdpong Daengsi
Department of Sustainable Industrial Management Engineering, Faculty of Engineering
Rajamangala University of Technology Phra Nakhon
1381 Pibul Songkhram Road, Bangsue, Bangkok, Thailand
Email: therdpong.d@rmutp.ac.th

1. INTRODUCTION

The modern chemical industry faces significant safety challenges due to the inherent hazards of handling dangerous substances. Operations carry high risks of industrial accidents, such as fires, leaks, and explosions, that threaten workers and nearby communities. A notable example is the explosion and fire at Ming Dih Chemical Co., Ltd. in Samut Prakan Province [1]. The facility, which produces expandable polystyrene (EPS) using flammable chemicals such as styrene monomer and pentane, suffered an explosion due to improper storage, causing the vaporization and ignition of hazardous substances. This incident caused extensive damage and casualties, emphasizing the need for systematic chemical risk management [2]. It also revealed broader gaps in workplace exposure monitoring, as many industries, including the pulp and paper sector, still lack continuous hazard monitoring, increasing occupational and environmental risks.

Although Thailand has laws regulating chemical storage, the framework remains inadequate for proactive risk assessment. Public awareness and transparency regarding environmental, health, and safety (EHS)-based risk management at storage sites are limited. Overlapping regulations have created legal complexity, and communities near industrial zones often lack access to clear information on hazards or safety measures. Essential technical resources, including chemical labels, safety data sheets (SDS), globally harmonized system (GHS) standards, and hazard communication materials, are frequently incomplete or poorly understood [3].

Globally and in Thailand, hazardous material risk assessment remains fragmented, with inconsistent legal frameworks and non-standardized practices. EHS methodologies offer a systematic approach to identify, evaluate, and prioritize chemical exposure risks. EHS assessments assign numerical values to hazard severity, likelihood, and frequency, producing a risk index that informs facility design, preventive measures, and safety interventions [4].

Between 2020 and 2025, ASEAN states have increasingly harmonized chemical management and occupational safety regulations [5]. Key measures include GHS-aligned chemical classification and labeling [6], ISO 45001 for occupational health, and ISO 14001 for environmental management [7]. Yet challenges remain, including inconsistent enforcement, limited small and medium-sized enterprises (SME) participation, fragmented risk methodologies, and disparities in national implementation [8]. Emerging digital tools and AI, such as predictive analytics and real-time monitoring, are increasingly applied to improve compliance and reduce human error [9]. This article systematically analyzes hazardous substance storage, risk assessment methodologies, and EHS-based approaches within legal and international standards. It proposes an enhanced EHS-based framework for Thailand that integrates Department of Industrial Works (DIW) regulations with global EHS standards to improve exposure monitoring, regulatory compliance, and stakeholder understanding [10]. Sections 2 to 5 discuss current methods, EHS frameworks, potential research directions, and study conclusions.

2. RISK ASSESSMENT METHODS, EHS-BASED RISK ASSESSMENT FOR STORING HAZARDOUS SUBSTANCES AND ASSOCIATED PRINCIPLES

2.1. Current risk assessment methods and other related approaches

Risk assessment methodologies for hazardous substance storage have continuously evolved to address increasingly complex industrial and regulatory environments. Over time, various models and frameworks have been developed to systematically identify, evaluate, and mitigate potential risks associated with storage facilities. These methodologies are designed to accommodate the diverse requirements of multiple stakeholders, including industrial operators, regulatory authorities, and consumers.

The first standard is ISO 14001 (environmental management system (EMS)), which provides a structured framework for environmental management within organizational settings. Its principal objective is to enable organizations to systematically and effectively identify, control, and mitigate the environmental impacts associated with their operational activities. Additionally, the standard emphasizes the promotion of efficient and sustainable resource utilization, including the reduction of energy consumption and minimization of pollutant emissions into the environment [11]. This international standard serves as a comprehensive foundation for organizations seeking to enhance environmental performance through structured and sustainable management practices [7]. Critically, the standard not only facilitates systematic environmental control but also encourages organizations to transition from reactive, compliance-based practices to integrated, sustainability-oriented governance, thereby ensuring measurable environmental performance improvement and continuous improvement over time [12]. From a strategic perspective, ISO 14001 extends beyond regulatory compliance by embedding environmental risk considerations into organizational governance and operational decision-making, thereby promoting preventive action, resource efficiency, and long-term sustainability performance aligned with international best practices [13].

The second standard is ISO 45001 (occupational health and safety management systems (OH&S)), which has been established to provide a comprehensive framework for the management of OH&S in the workplace. Its principal objective is to identify, assess, and control risks that may result in workplace accidents or hazards to employees. The standard emphasizes the development of a safe and supportive work environment with the aim of preventing incidents, safeguarding employee well-being, and enhancing overall organizational operational efficiency [11]. This standard provides organizations with a structured and systematic approach to integrating OH&S considerations into daily operations, thereby fostering a culture of risk awareness, legal compliance, and continuous improvement in workplace safety performance [7]. In accordance with the high-level structure (HLS) adopted across ISO management system standards, ISO 45001 emphasizes a systematic approach beginning with the analysis of the organizational context, identification of interested parties, and determination of OH&S risks and opportunities. This structure facilitates integration with other management systems, such as ISO 14001, thereby supporting a unified governance framework [5].

The next standard was issued by the European Chemicals Agency (ECHA), which is an institution of the European Union (EU) responsible for the collection, storage, and dissemination of information related to chemicals, particularly regarding their properties, toxicity, and potential impacts on human health and the environment. The ECHA database plays a pivotal role in facilitating the safe management of chemicals in accordance with the standards established under the Classification, Labelling, And Packaging (CLP) regulation. This regulation aligns with the GHS of classification and labelling of chemicals [13]. Furthermore, through the implementation of regulatory frameworks such as Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) and CLP, the agency strengthens harmonized chemical safety standards across member states, thereby reducing regulatory fragmentation within the internal market [14]. Moreover, the effectiveness of chemical risk management ultimately depends on the accuracy of industry-submitted data and the consistency of enforcement across member states, which may create variability in practical implementation [15].

The next method is the risk forecast and evaluation method (RFEM). This process involves determining the distance from the site of an incident, such as a chemical spill, to the designated area of interest, which may include terrestrial zones or water sources. The distance calculation is conducted in accordance with the methodology outlined in the digest of methodologies for forecasting possible accidents, catastrophes, and natural disasters, which serves as a comprehensive repository of approaches for predicting events with the potential to cause significant impacts [16]. The application of the RFEM method is critically important for evaluating the dispersion of toxic substances and the potential impacts extending from the point of origin to surrounding areas, including research sites located near chemical storage facilities. This methodology facilitates the systematic delineation of at-risk zones, thereby supporting planning, management, and mitigation strategies for unforeseen incidents. Its implementation is instrumental in guiding preparedness measures, establishing safety protocols, and informing the development of environmental and public health policies within affected regions [17]. Moreover, by incorporating predictive modeling techniques, the method strengthens preventive risk management and supports evidence-based contingency planning in areas surrounding hazardous chemical storage and handling facilities [16]. On the other hand, the reliability of RFEM projections depends heavily on the accuracy of input parameters, including meteorological conditions, chemical properties, terrain characteristics, and spill magnitude, which may introduce uncertainties into risk estimations [18].

The next approach was issued by the National Institutes of Health (NIH) in the United States (US). This agency serves as the principal federal institution responsible for conducting, facilitating, and supporting public health and biomedical research under the US Department of Health and Human Services (HHS). The NIH provides a comprehensive database accessible through the PubChem platform [19], which is frequently employed as a data source when original information regarding the half-life or biodegradation of specific hazardous chemicals is unavailable. Additionally, risk assessments of chemicals potentially affecting human health have incorporated evaluation results generated using the BIOWIN3 program developed by the US Environmental Protection Agency (EPA) [20]. Reliance on authoritative federal institutions enhances methodological credibility and promotes standardized approaches for evaluating chemical hazards and potential human health impacts [21]. However, although publicly available databases provide extensive information, variations in data sources, experimental conditions, and reporting standards may introduce inconsistencies that require careful validation before application in regulatory or policy decisions [22].

The next framework is Seveso III, which refers to Annex I of Directive 2012/18/EU of the European Parliament and of the Council, adopted on 4 July 2012. The directive establishes a regulatory framework for managing risks associated with major accidents involving hazardous substances. It provides criteria for classifying establishments handling hazardous chemicals into two principal categories: lower-tier and upper-tier establishments [23]. This classification is determined by the type and quantity of chemicals present, which in turn informs the implementation of safety management measures and accident prevention strategies at the organizational level [24]. Furthermore, Directive 2012/18/EU (Seveso III) operates in close alignment with broader European chemical regulatory frameworks, particularly the REACH regulation and the CLP regulation. While REACH focuses on the registration, evaluation, and authorization of chemical substances to ensure their safe manufacture and use, and CLP establishes harmonized criteria for classification and hazard communication, Seveso III specifically addresses the prevention and control of major industrial accidents involving hazardous substances [3].

In addition, compliance with the DIW refers to adherence to the DIW notification on the guidelines for the storage of chemicals and hazardous substances, B.E. 2550 (2007) [25]. This regulation was established to govern and supervise the safe storage of chemicals and hazardous substances. It also encompasses the DIW regulations on hazard identification, risk assessment, and the formulation of risk management plans, B.E. 2543 (2000) [26]. This regulatory framework supports the systematic identification of hazards, evaluation of potential risks, and development of structured risk management strategies to prevent and mitigate the impacts of chemicals and hazardous substances within industrial establishments [12]. In accordance with the risk assessment standards outlined in sub-sections 2.1, the overall procedure is summarized in Figure 1. The figure presents the main stages of the risk assessment process in a clear and structured sequence and illustrates the logical relationships among each stage to ensure a systematic and comprehensive evaluation.

Figure 1. Standard flowchart for risk assessment [11]–[13], [17], [20], [24]

Moreover, recent ASEAN and global chemical safety frameworks have increasingly emphasized integrated and proactive chemical management approaches. ASEAN has advanced chemical safety through initiatives such as the Hosprep Programme (2025) [27], which aims to strengthen hospital preparedness for chemical emergencies, as well as through multisector coordination workshops designed to enhance regional capabilities in the detection, response, and management of chemical incidents. These workshops, organized by the UK Health Security Agency, focus on improving intersectoral coordination and refining strategies for effective chemical incident management across ASEAN member states [28].

In 2025, Japan's Ministry of the Environment issued the global framework on chemicals (GFC) implementation plan in alignment with the international GFC adopted in Germany in 2023. The plan emphasizes comprehensive lifecycle management of chemicals, covering production, usage, and disposal, while promoting multisector collaboration to protect both environmental and human health [27]. In addition, the global initiative Responsible Care®, led by Cefic, highlights the continuous improvement of chemical safety management. The program aims to enhance environmental, health, safety, and security performance through voluntary commitments and proactive stewardship practices [3].

2.2. EHS risk assessment principle

In practice, discussions regarding the management of EHS risks often emphasize safety-related hazards [23]. Nevertheless, safety constitutes only one facet of a comprehensive EHS risk management framework. Effective EHS risk management necessitates the evaluation and mitigation of risks across multiple dimensions spanning the entire organization [29]. These dimensions include environmental risks, such as pollution, waste management, and the sustainable use of resources; occupational health risks, encompassing employee well-being and work-related illnesses; and safety risks, including accidents, injuries, and emergency situations [30]. This risk assessment adopts a quantitative approach by evaluating both the likelihood of occurrence and the potential severity of chemical incidents. The overall risk score is calculated using (1). Each factor is assigned a numerical value based on predefined criteria to ensure consistency, transparency, and objectivity throughout the assessment process [23].

$$Risk\ score = Likelihood \times Severity \tag{1}$$

In the process of hazard identification, approximately seven analytical tools or methodologies have been developed to support systematic risk assessment. Each tool serves a specific purpose and is designed for particular applications, thereby enabling comprehensive and effective identification of potential hazards [31]. Collectively, these tools improve the reliability and thoroughness of the hazard identification process. Commonly used tools include checklists, what-if analysis, hazard and operability study (HAZOP), fault tree analysis (FTA), event tree analysis (ETA), failure modes and effects analysis (FMEA), and the analytic hierarchy process (AHP).

Checklist is an effective instrument for evaluating workplace safety, primarily focusing on identifying potential hazards that may arise during operational activities. Developed in accordance with established safety standards, engineering guidelines, and applicable legal requirements, the assessment typically consists of a structured set of questions related to work processes, equipment design, and operational procedures [32]. The data obtained from inspections are systematically collected and analyzed to identify hazards, thereby providing a foundation for the development of appropriate hazard control and prevention measures [1].

What-if analysis is used to systematically identify and evaluate potential hazards in industrial processes through a structured “What if...” approach. It generates hypothetical scenarios to explore possible deviations from normal operations and assess their potential consequences. Based on this analysis, it supports the development of practical strategies to control, prevent, or mitigate risks during production and operational activities [1]. In contrast, HAZOP is used to systematically identify hazards and operational issues within industrial systems, including design deficiencies and unintended deviations. It applies to a structured, hypothesis-driven approach to examine possible deviations under varying operating conditions. Through this process, HAZOP helps anticipate and mitigate risks, thereby enhancing operational safety and efficiency [1].

FTA is an analytical tool used to identify and evaluate hazards, particularly those associated with past or potential major incidents. Its primary objective is to systematically examine underlying causes through a structured top-down approach that considers both historical accidents and potential disaster scenarios [33]. The analysis begins by identifying the primary event and then decomposing it into contributing sub-events, such as machinery malfunctions, equipment failures, or operational deviations. By examining the relationships among these events and influencing factors, FTA enables precise identification of root causes and supports preventive measures and effective risk management [1].

Similarly, ETA is an analytical tool used to identify potential hazards and evaluate the consequences arising from an initiating event. The method focuses on predicting and examining subsequent event sequences, systematically assessing impacts such as machinery damage, equipment failure, or operational errors that may lead to adverse outcomes. ETA enables structured evaluation of event progression, estimation of recurrence probability, and assessment of existing safety systems. Through this process, it helps identify deficiencies or vulnerabilities that may reduce the effectiveness of control and prevention measures [1]. FMEA is a systematic and effective tool for risk assessment and analysis, with particular emphasis on identifying potential failure modes within systems, processes, or machinery components. The primary objective of FMEA is to identify and evaluate potential risks, thereby supporting the planning and implementation of measures aimed at reducing the probability of failure and mitigating impacts on the overall system [34].

Finally, the AHP is a decision-making tool widely used to prioritize factors involved in the risk assessment process. Its fundamental principle is the decomposition of a problem into a hierarchical structure consisting of the main objective, major criteria, and sub-criteria. AHP facilitates pairwise comparison of the relative importance of each factor, converting expert knowledge, judgments, and qualitative perceptions into quantitative values. These values are subsequently applied as weighted inputs in a systematic analysis to establish the prioritization and ranking of risk factors [35].

2.3. Principles of environmental risk assessment

Environmental risk assessment is a systematic process for analyzing and evaluating the probability that chemicals or specific activities may exert adverse effects on the environment. This assessment typically employs tools based on ecotoxicological parameters, which facilitate the determination of the toxicity of substances on living organisms across various ecosystems. Examples of parameters commonly utilized in such assessments include: i) effective concentration 50% (EC_{50})-aquatic toxicity: the concentration of a substance at which 50% of aquatic organisms exhibit adverse effects, such as decreased mobility or reproductive impairment [36]; ii) log bioconcentration factor (BCF): this value indicates the tendency of chemicals to accumulate in aquatic organisms by comparing the concentration of the substance in the tissues of the organisms to that in the water [37]; and iii) log octanol/water partition coefficient (K_{ow}): this value represents the substance’s solubility capacity in fats compared to water, which is related to its absorption into the body and accumulation in living organisms [38].

The analysis of such data enables environmental scientists and regulatory authorities to comprehensively evaluate ecosystem risks. By systematically examining exposure levels, environmental pathways, and potential ecological impacts, it provides a clear understanding of the severity and likelihood of adverse effects. This structured assessment supports informed and effective decision-making regarding chemical management and related regulatory actions [39].

2.4. Principles of health risk assessment

Health risk assessment is a systematic process used to evaluate the likelihood that individuals may experience adverse health effects due to exposure to chemicals or other environmental risk factors. It provides a structured framework for identifying hazards, estimating exposure levels, and characterizing potential health impacts. The assessment consists of multiple stages, with one of the key steps encompassing [40].

2.4.1. Dose-response assessment, also known as toxicity assessment

This assessment emphasizes the quantitative evaluation of the relationship between the level of chemical exposure and the resulting health effects, including injuries or diseases. Because most chemicals cause adverse effects only when exposure exceeds a certain threshold, effective chemical risk assessment requires systematic analysis of the exposure-response relationship [41]. Evaluation data are typically derived from animal toxicological studies or human epidemiological research, with priority given to information reflecting actual conditions of the target population. For non-carcinogenic chemicals, assessments generally assume that adverse effects occur only above a defined exposure threshold, and reference values are commonly used to support this determination as follows: i) lowest-observed-adverse-effect level (LOAEL): the lowest observed adverse effect level [42]; ii) no-observed-effect level (NOEL): the no observed adverse effect level [43]; and iii) no-observed-adverse-effect level (NOAEL): the maximum dose that does not cause harmful effects to the body [42].

2.4.2. Exposure assessment

Exposure assessment is a systematic process employed to estimate the quantity or concentration of chemicals entering the human body. Exposure may occur via multiple pathways, including inhalation, ingestion, or dermal absorption. For instance, the following reference values are commonly utilized [44]: i) acute toxicity-oral LD_{50}: it is the quantity of a substance that causes acute toxicity when ingested and results in the death of 50% of the test animal group [45]; ii) acute toxicity-dermal LD_{50}: it refers to the quantity of a substance that induces acute toxicity via dermal exposure, resulting in the mortality of 50% of the test animals [46]; and iii) acute toxicity-inhalation LC_{50}: it denotes the concentration of a substance in the air that produces acute toxicity via inhalation, resulting in the mortality of 50% of the test animals [47].

2.5. Principles of risk assessment in safety evaluation

The assessment of safety risks associated with chemical storage necessitates a comprehensive analysis and evaluation of activities that may precipitate accidents. This process is critical for the development and implementation of effective safety prevention and control measures. Such evaluations may be conducted with reference to various factors, including as follows [48].

2.5.1. Quantity of chemical storage

The assessment must consider variations in the quantities of chemicals stored over time, particularly the storage of unusually large or small amounts, as these factors affect both the probability of accidents and the potential severity of their consequences [49]. Fluctuations in storage levels can significantly influence risk profiles by altering exposure potential and hazard intensity. Therefore, evaluating these variations is essential to ensure accurate risk estimation and effective safety management.

2.5.2. Fire prevention and suppression system for hazardous chemicals

The planning and installation of fire protection and suppression systems in chemical storage areas must consider the specific characteristics and classifications of the chemicals to ensure effective fire prevention and control [50]. Different chemical properties, such as flammability, reactivity, and toxicity, require appropriate system design and compatible extinguishing agents. Therefore, proper evaluation of chemical classifications is essential to enhance safety performance and minimize potential fire-related damage.

2.5.3. Activities conducted in an open manner

Activities involving the handling of chemicals in open systems, such as chemical filling or random sampling, must be subjected to risk assessment and the implementation of appropriate preventive measures, owing to the increased potential for chemical exposure and accident occurrence [51]. Open handling processes elevate the likelihood of leaks, spills, or direct contact with hazardous substances. Therefore, systematic risk evaluation and strict control measures are essential to reduce exposure and prevent operational incidents.

2.5.4. Management of facilities and equipment in the warehouse

The management of storage areas, including vehicles and equipment utilized in warehouse operations, must be subject to regular inspection and control to prevent accidents and mitigate potential damage [52]. Routine inspections help identify mechanical defects, operational hazards, and unsafe practices that may increase accident risks. Therefore, consistent monitoring and maintenance are essential to ensure safe warehouse operations and minimize potential losses.

2.5.5. Safety measures and regulations

Rigorous adherence to established measures, regulations, and procedures is essential for effectively mitigating risks and preventing accidents in chemical storage operations [53]. Compliance ensures that safety standards are consistently implemented and that potential hazards are systematically controlled. Therefore, strict enforcement and continuous monitoring of these requirements are necessary to maintain operational safety and reduce the likelihood of incidents.

2.5.6. Equipment maintenance plan

The development and ongoing maintenance of equipment associated with chemical storage constitute critical factors in ensuring safe operating conditions and minimizing the risk of accidents [48]. In accordance with the EHS risk assessment framework, risk assessments can be categorized into three primary types. Detailed descriptions are provided in sub-sections 2.3 to 2.5, while the fundamental concepts are summarized in Figure 2, which depicts the systematic principles and processes underlying EHS-based risk assessment. In accordance with the EHS risk assessment framework, each category of evaluation delineates the potential hazards and underlying contributing factors related to the storage of hazardous materials, as summarized in Figure 3. This structured categorization facilitates the systematic identification of risks associated with storage conditions, operational practices, and environmental influences. Consequently, it provides a comprehensive basis for analyzing vulnerabilities and implementing appropriate risk control measures.

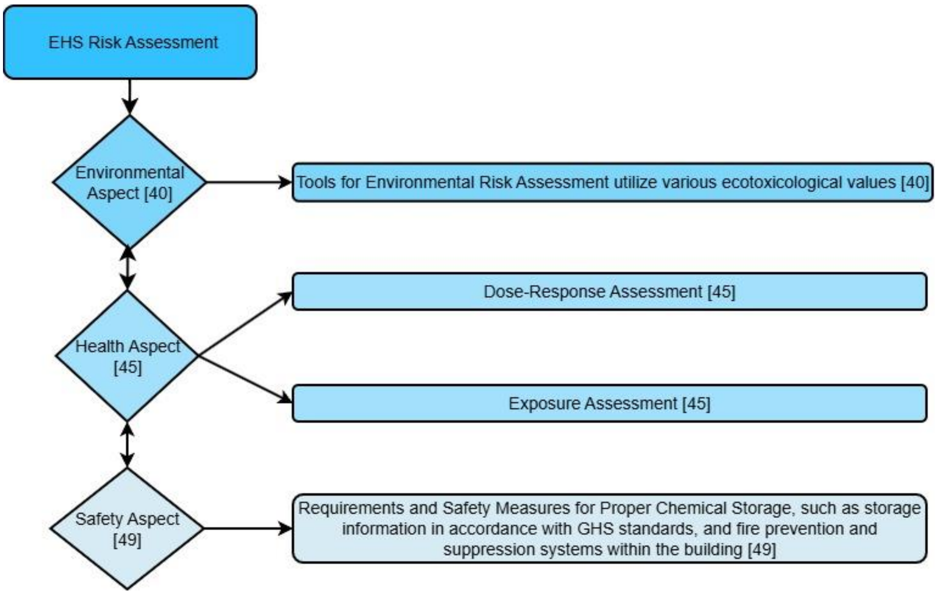

Figure 2. Summarizing the principles and tools for EHS assessment [39], [44], [48]

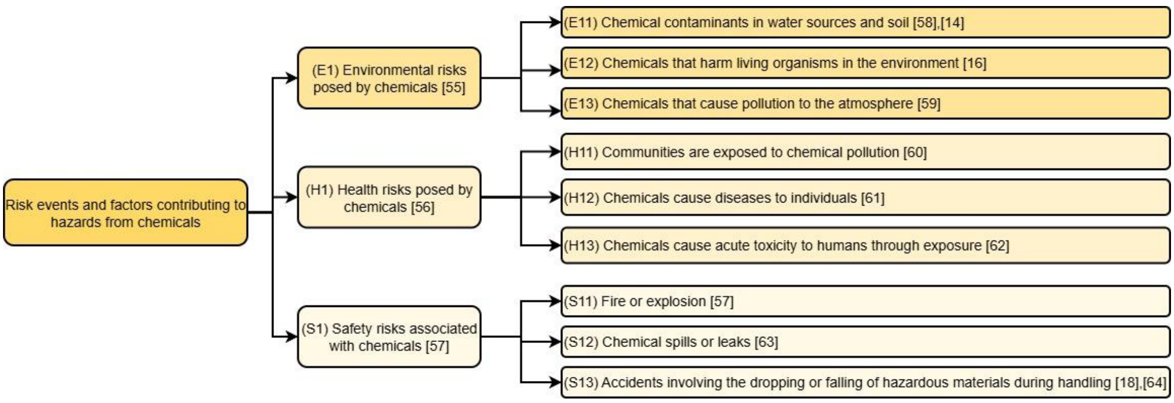

Figure 3. Flowchart of risk events and factors contributing to chemical hazard risks [14], [16], [18], [54]–[63]

3. METHOD
3.1. Research conceptual framework
This study adopts a conceptual framework to investigate and evaluate EHS risks through a multidimensional approach, integrating the core EHS domains. The research commences with a review of the DIW risk assessment guidelines, followed by a comparative analysis with international standards, including ISO 14001 (EMS) and ISO 45001 (OH&S). A gap analysis will be performed to identify deficiencies or weaknesses within the current Thai framework. Based on the findings, an integrated EHS risk assessment model will be developed, providing a more balanced, compliant, and internationally aligned methodology for industrial risk evaluation. This multidimensional framework enables a balanced evaluation across EHS domains. The risk assessment methodology is aligned with DIW guidelines in Thailand while also incorporating international standards for comparative analysis, thereby identifying gaps and informing the development of an integrated EHS risk assessment conceptual model.

3.2. Selection using PRISMA
The researcher conducted a comprehensive systematic review of relevant literature using the PRISMA concept to inform the investigation. Initially, a total of 362 studies were identified. Following screening, 82 studies were found to contain duplicate content, 149 were deemed unrelated to the research objectives, and 57 were inaccessible in full text. Consequently, 74 studies were determined to be both accessible and pertinent to the investigation. The selection process is summarized in the flowchart presented in Figure 4.

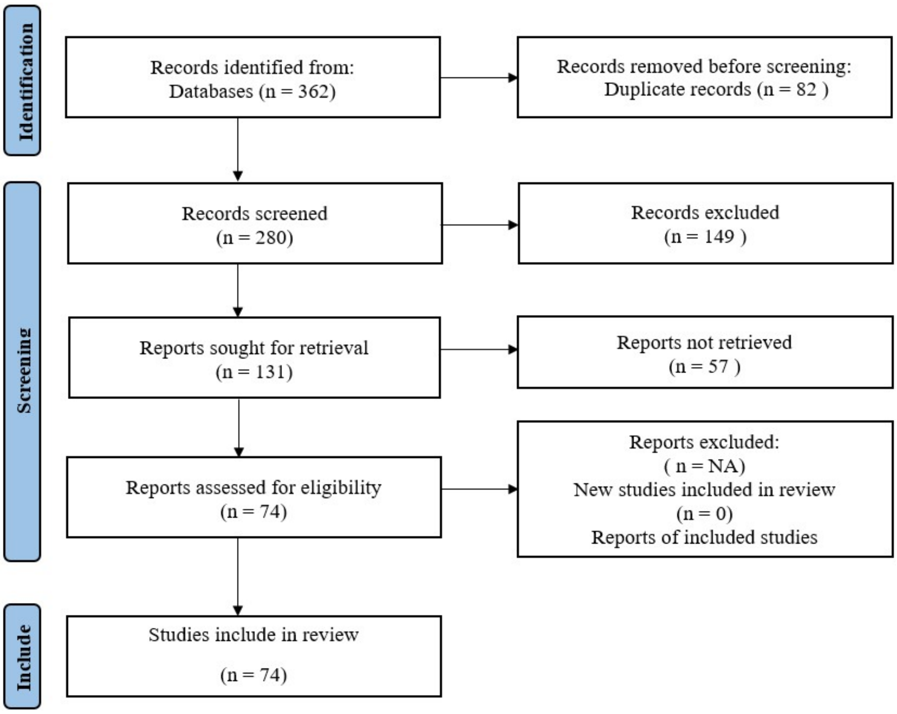

Figure 4. Research selection process following the PRISMA concept

3.3. Data sources
Primary data were collected via a literature review systematically on hazardous substance storage risk assessment. Sources from ScienceDirect, Google Scholar, and the DIW website were selected for reliability and relevance. The systematic review, focusing on publications from 2020 to 2025, incorporated peer-reviewed research, academic studies, and regulatory guidance to capture current strategies and practices.

3.4. Compliance valuation
Compliance is assessed by comparing operational practices against regulatory requirements, identifying gaps, and recommending appropriate corrective actions. Thai legislation, notably the DIW announcement on the guidelines for the storage of chemicals and hazardous substances, B.E. 2550, serves as

a primary reference. The evaluation encompasses the following key aspects [64]. This includes evaluating chemical storage to ensure container integrity, appropriate segregation, and effective spill containment in accordance with DIW guidelines, with any instances of non-compliance duly documented. The availability and accuracy of SDS for all chemicals are verified in accordance with the Occupational Safety and Health Administration (OSHA) and GHS standards, with any missing or incomplete information identified. Employee training programs and the proper use of personal protective equipment (PPE) are evaluated in alignment with ISO 45001, and any deficiencies are systematically documented. Risk management and emergency preparedness are assessed through the evaluation of plans, procedures, and drills in accordance with Seveso III directives and applicable local regulations, with any gaps duly identified. Additionally, chemical inventories and reporting processes are reviewed to ensure accuracy and timely submission to regulatory authorities, as mandated by ECHA and DIW regulations. Furthermore, compliance evaluation encompasses the analysis of chemical risks to ensure alignment with international standards, including EU REACH for chemical registration and safety [15], US OSHA for OH&S, and Japan's Chemical Substances Control Law (CSCL) for regulating chemical production and use to prevent environmental and health hazards [21]. Such compliance assessments enable organizations to ensure that the storage and management of hazardous substances are conducted safely, in full accordance with legal requirements, and in alignment with international EHS standards.

4. RESULTS AND ANALYSIS

4.1. Key findings from literature and case analysis

The chemical industry continues to face significant safety challenges arising from the handling of flammable, reactive, and toxic substances. The explosion at Ming Dih Chemical Co., Ltd. in Samut Prakan, Thailand, underscores the severe consequences of inadequate storage practices, insufficient risk controls, and lapses in regulatory compliance. Despite the existence of regulations issued by the DIW, enforcement remains weak, legal frameworks are fragmented, and critical safety information is often inaccessible. Moreover, inconsistent implementation of SDS, GHS labeling, and hazard communication further compromises safety in hazardous material storage environments.

4.2. Regulatory and technical gaps

The analysis highlights critical gaps in the risk assessment of hazardous material storage, including insufficient monitoring based on outdated data, inconsistent risk assessment protocols lacking alignment with international standards, limited public awareness and transparency, and regulatory fragmentation resulting from overlapping laws that generate confusion and impede timely implementation. These weaknesses reduce the effectiveness of hazard identification and compromise the reliability of risk management practices. Consequently, addressing these deficiencies is essential to strengthen regulatory coherence, improve data accuracy, and enhance overall safety performance.

4.3. Comparative assessment of existing frameworks

A comparative evaluation of multiple international and national frameworks was undertaken to identify best practices for EHS-based risk assessment. This comparison enabled a systematic analysis of their principles, criteria, and implementation approaches across different regulatory contexts. The related key frameworks are listed in Table 1.

The frameworks outlined above exhibit varying degrees of comprehensiveness, applicability, and accessibility. A comparative analysis reveals differences in scope, methodological structure, and practical implementation across contexts. However, the evaluation indicates that most systems are designed to operate independently, lacking full integration across the EHS domains [65].

Table 1. A comparative analysis of international and national risk assessment frameworks

Framework	Key features
ISO 14001	EMS focusing on sustainable operations and pollution control.
ISO 45001	Occupational health and safety standard aimed at hazard identification and risk prevention.
ECHA/GHS	Global standards for chemical classification, labeling, and hazard communication.
RFEM	A predictive model for calculating chemical dispersion and defining risk zones.
NIH/BIOWIN3	Scientific tools and databases for evaluating chemical toxicity and environmental persistence.
Seveso III Directive	EU directive classifying high- and low-risk facilities and guiding major accident prevention strategies.
DIW regulations (Thailand)	National laws governing chemical storage, hazard identification, and risk management planning.

4.4. Comparative analysis of international regulatory systems

To address the challenges faced in Thailand, a comparative analysis was undertaken of major international chemical regulatory frameworks, including EU REACH, US OSHA, and Japan CSCL. This comparison offers valuable insights into best practices and lessons learned, which can inform the development of an enhanced risk assessment model. Therefore, the comparison highlights several key lessons that can be applied to improve Thailand's chemical risk assessment framework, as outlined follows:

i) Proactive risk assessment (from REACH and CSCL): in contrast to Thailand's predominantly reactive framework, both EU REACH and Japan CSCL prioritize pre-market evaluation, early hazard identification, and continuous chemical tracking [22].
ii) Public data access (from REACH): REACH's chemical safety reports (CSR) provide transparency that fosters public trust and supports informed decision-making, representing a critical gap in Thailand's chemical risk management [66].
iii) Integration with EHS (global best practice): international frameworks increasingly adopt integrated EHS management systems, whereas Thailand's DIW guidelines remain fragmented and primarily operational in focus [67].

4.5. Development of an integrated EHS-based risk assessment approach

To address the identified gaps, this study proposes a comprehensive, multidimensional risk assessment model for the storage of hazardous substances, grounded in EHS principles and integrating DIW regulations with international standards, including ISO 14001, ISO 45001, and GHS. The model is operationalized through a structured questionnaire that evaluates severity, likelihood, exposure, and the effectiveness of control measures, thereby providing a streamlined yet robust framework for risk evaluation, regulatory compliance, and continuous improvement. This integrated approach offers several key advantages: it facilitates alignment between national and international regulatory frameworks, enhances accessibility to hazard-related information, promotes proactive risk mitigation, and strengthens communication among regulatory authorities, industry stakeholders, and local communities.

To address Thailand's current challenges, this study conducted a comparative analysis of key international chemical regulatory frameworks, namely EU REACH, US OSHA, and Japan CSCL, as shown in Table 2 [68]. The analysis examined their regulatory structures, risk management mechanisms, and enforcement approaches to identify transferable practices. The evaluation highlights best practices and essential policy recommendations to enhance the effectiveness of chemical risk assessment models in Thailand.

4.6. Development of practical tools

Literature underscores an increasing adoption of digital and artificial intelligence (AI)-driven tools in EHS risk management, encompassing real-time sensors, predictive analytics, and automated reporting, which collectively enhance situational awareness and incident response [28]. Nevertheless, challenges, including data quality, implementation costs, and workforce competency, constrain the widespread adoption of these technologies in regions such as Southeast Asia [69]. Concurrently, practical instruments such as checklists, mobile applications, and structured questionnaires designed in accordance with EHS principles and DIW regulations can facilitate routine assessments by SMEs and local regulatory authorities. These tools help translate complex regulatory requirements into practical procedures and support consistent implementation. As a result, stakeholders are better equipped to manage compliance obligations and control associated risks effectively.

4.7. Implications for ASEAN harmonization, policy, industrial zones, SMEs, and cross-border chemical logistics

This study aligns with ASEAN initiatives to harmonize chemical safety standards, emphasizing consistent regulatory enforcement, stakeholder training, and unified classification systems. The proposed EHS-based framework offers a standardized yet adaptable model consistent with GHS and ISO standards [3]. Within industrial zones, EHS assessments facilitate the identification of high-risk operations, guide inspections, and support environmental governance, accident prevention, and investor confidence [27]. For SMEs, simplified assessment tools and digital compliance systems enhance awareness, training, and regulatory adherence, mitigating resource constraints. In cross-border chemical logistics, harmonized risk management fosters safer trade and ensures alignment with international frameworks, including EU REACH, US OSHA, and Japan's CSCL. The integration of AI-driven monitoring and predictive analytics enables real-time risk management, promoting regional safety, sustainable development, and ASEAN-wide standardization [3].

Table 2. Comparative overview of major chemical safety frameworks

Aspect	EU REACH	US OSHA (HazCom)	Japan CSCL	Thailand (DIW)
Risk standard	REACH	OSHA-hazard communication standard	CSCL	DIW guidelines
Scope	All chemical substances manufactured or imported in the EU (≥1 ton per year)	Workplace chemical safety, labeling, SDS, and training	Regulates new and existing chemicals, environmental risks, and industrial chemicals	Focus on industrial chemical storage and hazard identification, emphasizing safe storage practices, hazard recognition, and basic risk control measures within industrial facilities.
Risk assessment approach	Life-cycle-based, including human health and environmental risk assessment	Workplace-specific hazard communication with qualitative risk evaluation	Classifies chemicals based on toxicity and persistence, with pre-market assessment.	Storage-focused risk identification with an emphasis on qualitative risk ranking to prioritize hazards based on likelihood and potential consequences.
Data requirements	Extensive toxicology, exposure, and use-pattern data are required, along with strict documentation.	SDSs, GHS-compliant labeling, and mandatory employee training	Requires biodegradability, bioaccumulation, and toxicity testing prior to import or manufacture.	Limited mandatory toxicological data requirements, relying primarily on basic chemical hazard identification rather than comprehensive exposure or lifecycle-based risk evaluation.
Public transparency	High, with CSRs published online	Moderate, with SDS access and labeling visible to workers	Limited, with some data available but primarily focused on manufacturer compliance.	Low-No public database of hazardous substances at specific facilities
GHS implementation	Fully integrated and enforced	Fully implemented through HazCom 2012	Partially implemented, aligned with GHS while incorporating country-specific regulatory adaptations.	Partially adopted; implementation inconsistent across sectors
Enforcement mechanism	Strong, with centralized EU ECHA oversight and strict penalties	OSHA inspections and fines ensure employer accountability.	Central government oversight via Ministry of Economy, Trade and Industry (METI), Ministry of Health, Labor and Welfare (MHLW), and Ministry of the Environment (MOE).	Enforcement effectiveness varies by province, with limited inspection capacity constraining consistent regulatory oversight and timely compliance monitoring across industrial facilities.
Strengths	Comprehensive, science-based, and promotes innovation and data sharing	Strong workplace protections, including the employee right-to-know.	Preemptive control measures are applied before market entry, with a strong emphasis on environmental protection and the prevention of long-term ecological and human health impacts.	Practical for achieving basic regulatory compliance and well understood by local industries, making it relatively easy to apply within existing operational and administrative practices.
Weaknesses/gaps	Costly and complex for SMEs	Does not cover all chemicals and is limited to the occupational setting.	Lower levels of transparency, coupled with complex and time-consuming bureaucratic approval processes.	Fragmented, lacks real-time monitoring and integration with global standards

4.8. Research challenge and opportunities

This article aims to synthesize and critically analyze findings from prior studies selected from reputable academic databases, including Google Scholar and Scopus. The study employs secondary data that were systematically analyzed and compared to identify suitable approaches for assessing EHS considerations. The research primarily focuses on developing a more effective EHS assessment framework to mitigate risks associated with hazardous material storage and enhance safety throughout operational processes. Insights derived from this literature synthesis are intended to support the development of methodologies or tools for evaluating EHS performance in the context of sustainable hazardous substance management. A systematic review of previous studies on EHS risk assessment methods revealed that most investigations adopted case study approaches, focusing on risk management practices related to hazardous material storage in warehouses and industrial facilities handling large quantities of hazardous substances.

Regarding challenges in forecasting and regulatory compliance, a critical issue identified in the literature is the insufficient integration of governmental legal requirements with toxicological data in systematic risk assessments. Existing data have not been fully utilized for comprehensive analyses, resulting in limited stakeholder awareness of risks as defined by regulatory authorities. Consequently, a significant gap remains between statutory requirements and their practical implementation within organizational operations [57], [70].

In terms of data challenges in risk assessment, EHS evaluations frequently encounter limitations caused by insufficient data availability. The absence of standardized guidelines for managing areas involving hazardous chemical usage or storage also remains a significant challenge. Furthermore, a notable gap persists between theoretical risk assessment frameworks and their practical implementation, creating obstacles to the effective development and application of EHS risk management systems [71].

With respect to data-related issues in integrating risk assessment processes, previous studies indicate that EHS risk assessments are conducted using diverse approaches and methodologies. Although efforts have been made to integrate these practices to improve EHS management decision-making, conventional risk assessment and life cycle assessment (LCA) mainly focus on impacts to human health and ecosystems, while safety issues related to hazardous material storage are often insufficiently addressed [72]. In addition, limited integration of technological solutions with methodologies aligned to international standards has resulted in fragmented assessments and incomplete data integration, which remain critical barriers to comprehensive risk management [73].

To address these limitations, a comprehensive EHS-based risk assessment framework for hazardous material storage was developed by integrating EHS dimensions. Environmental risks include leakage incidents and improper storage conditions, health risks involve impacts on employees and nearby communities, and safety risks relate to accidents, fires, and explosions. The framework incorporates both qualitative and quantitative approaches, while the AHP is applied to improve assessment accuracy and robustness. The framework also integrates domestic regulations issued by the DIW, together with relevant international standards to address existing challenges more effectively. In addition, a practical assessment tool, implemented as either a structured checklist or a software prototype, was developed and tested in an operational workplace to evaluate its applicability and effectiveness. The analysis demonstrates that each identified EHS risk assessment issue is supported by relevant scholarly literature, as summarized in Table 3 (see Appendix).

5. DISCUSSION

This study reveals persistent structural and operational weaknesses in Thailand's hazardous chemical management system, particularly with respect to storage control, regulatory enforcement, and risk communication. The explosion at Ming Dih Chemical Co., Ltd. in Samut Prakan illustrates the severe consequences of fragmented oversight, inadequate storage practices, and limited public access to hazard information. Although regulatory mechanisms exist under the DIW, the findings indicate that enforcement capacity, inter-agency coordination, and data transparency remain insufficient to ensure effective implementation. Compared with more preventive and life-cycle-based regulatory systems in the EU, such as REACH regulation and Directive 2012/18/EU, Thailand's framework remains predominantly reactive and operational in orientation. International systems emphasize pre-market evaluation, continuous chemical tracking, hazard transparency, and structured accident prevention planning, whereas Thai regulations focus largely on storage inspection and qualitative risk identification. This divergence indicates that regulatory effectiveness depends not merely on the existence of legal instruments but critically on their integration, enforcement rigor, and transparency mechanisms.

The comparative analysis further demonstrates that most international frameworks including ISO standards issued by the international organization for standardization, chemical classification systems, predictive risk models, and national regulatory regimes tend to operate in parallel rather than within fully integrated EHS governance structures. This fragmentation limits holistic risk visibility, particularly in hazardous material storage contexts where environmental impacts, worker safety, and community health risks intersect. Moreover, weaknesses in SDS implementation, inconsistent GHS labeling, and limited accessibility of public databases reduce stakeholder awareness and undermine emergency preparedness. Data-related challenges also persist, as risk assessments frequently rely on incomplete toxicological information, outdated monitoring systems, and limited real-time technological integration. While predictive tools and digital innovations offer promising opportunities for improved risk forecasting and compliance monitoring, their effectiveness depends on data accuracy, institutional capacity, and workforce competency factors that remain uneven, particularly among SMEs.

In response to these gaps, the proposed integrated EHS-based risk assessment framework represents a strategic advancement by combining environmental, occupational health, and industrial safety considerations within a unified analytical structure. By incorporating both qualitative and quantitative approaches, including the AHP and aligning domestic regulations with international standards, the model enhances methodological rigor, regulatory coherence, and practical applicability. Beyond technical improvements, the study underscores the importance of policy reform, capacity building, digital infrastructure development, and strengthened inter-agency coordination to ensure sustainable implementation. Overall, the findings indicate that transitioning from a fragmented and reactive system to a proactive, transparent, and integrated EHS governance model is essential for improving chemical safety performance, preventing major industrial accidents, and supporting long-term sustainable development in Thailand and the broader ASEAN region.

6. CONCLUSION

This study reveals that current EHS risk assessment methods exhibit notable limitations that may contribute to industrial accidents, chemical spills, and adverse impacts on worker health and the environment. Key deficiencies include inadequate integration of toxicological data with legal requirements, the absence of unified standards, limited localization of international methodologies, and a lack of practical assessment tools for workplace implementation. Focusing on chemical storage within Thailand’s industrial sector, the research identifies systemic weaknesses such as improper chemical segregation, outdated storage practices, insufficient exposure monitoring, inadequate emergency preparedness, limited public transparency, and fragmented regulatory frameworks, as reflected in incidents such as the explosion at Ming Dih Chemical Co., Ltd.. Although existing approaches, including ISO 14001, ISO 45001, RFEM, and toxicological database tools, provide structured assessment frameworks, their effectiveness in Thailand remains constrained by procedural complexity, inconsistent enforcement, and limited digital integration under the oversight of the DIW. The findings demonstrate that an EHS-based risk assessment framework offers a more integrated and proactive model by aligning EHS dimensions with international standards; however, gaps in regulatory clarity, data transparency, and standardization persist. Therefore, the study proposes a standardized and practical EHS-based framework aligned with DIW guidelines and international best practices to enable proactive risk identification, strengthen stakeholder awareness, support ASEAN harmonization, and enhance sustainable hazardous substance management in Thailand.

ACKNOWLEDGMENTS

This research was supported by Rajamangala University of Technology Phra Nakhon.

FUNDING INFORMATION

No funding was received for this research.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Hengheng Jarunongkran	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Therdpong Daengsi	✓	✓		✓			✓			✓		✓	✓	✓

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [TD], upon reasonable request.

REFERENCES

[1] HISO, "Ming dih factory explosion: lessons from a chemical factory disaster," *Thai Health Report*, 2022, pp. 59-63.

[2] Work Safe BC, "Explosion or fire of pentane released from expandable polystyrene (EPS) foam blocks," worksafebc.com. Accessed: Oct. 23, 2025. [Online]. Available: https://www.worksafebc.com/en/resources/health-safety/risk-advisory/explosion-or-fire-of-pentane-released-from-expandable-polystyrene-eps-foam-blocks

[3] G. C. Ta, "GHS implementation to strengthen global chemical hazard communication: will we ever get there?," *ACS Chemical Health and Safety*, vol. 28, no. 3, pp. 153–158, May 2021, doi: 10.1021/acs.chas.0c00114.

[4] F. Fatemi, A. Dehdashti, and M. Jannati, "Implementation of chemical health, safety, and environmental risk assessment in laboratories: a case-series study," *Frontiers in Public Health*, vol. 10, Jun. 2022, doi: 10.3389/fpubh.2022.898826.

[5] M. Podrecca, M. Molinaro, M. Sartor, and G. Orzes, "The impact of ISO 45001 on firms' performance: an empirical analysis," *Corporate Social Responsibility and Environmental Management*, vol. 31, no. 5, pp. 4581–4595, Sep. 2024, doi: 10.1002/csr.2782.

[6] M. F. H. A. Yazid, G. C. Ta, and M. Mokhtar, "Classified chemicals in accordance with the globally harmonized system of classification and labeling of chemicals: comparison of lists of the European Union, Japan, Malaysia and New Zealand," *Safety and Health at Work*, vol. 11, no. 2, pp. 152–158, Jun. 2020, doi: 10.1016/j.shaw.2020.03.002.

[7] S. M.-Reyes, J. C.-Cárdenas, and A. P.-Rojano, "Implementation of a methodology for the integration of management systems based on NTC-ISO 14001:2015 and NTC-ISO 45001:2018: a case study in the construction sector," *Ingeniare*, vol. 30, no. 4, pp. 769–779, 2022, doi: 10.4067/S0718-33052022000400769.

[8] F. Hendra, R. Mohammad, A. Amrin, N. Maarop, and T. Y. Zagloel, "Systematic literature review of risk assessment techniques, standard and guidelines for railway," *International Journal of Technology*, vol. 15, no. 4, pp. 1148–1161, 2024, doi: 10.14716/ijtech.v15i4.6384.

[9] A. T. Aderamo, H. C. Olisakwe, Y. A. Adebayo, and A. E. Esiri, "AI-driven HSE management systems for risk mitigation in the oil and gas industry," *Comprehensive Research and Reviews in Engineering and Technology*, vol. 2, no. 1, pp. 1–22, Oct. 2024, doi: 10.57219/crret.2024.2.1.0059.

[10] B. Tepparit, N. A.-Eam, K. Warunsin, L. Sriratana, W. Kongsong, and B. Harnphanich, "Application of inspection programs for risk assessment by factory control laws," *International Journal on Advanced Science, Engineering and Information Technology*, vol. 14, no. 5, pp. 1673–1682, 2024, doi: 10.18517/ijaseit.14.5.19959.

[11] P. Liu, M. Shen, and Y. Geng, "Risk assessment based on failure mode and effects analysis (FMEA) and WASPAS methods under probabilistic double hierarchy linguistic term sets," *Computers and Industrial Engineering*, vol. 186, Dec. 2023, doi: 10.1016/j.cie.2023.109758.

[12] H. T. T. Ngo, P. Watchalayann, D. B. Nguyen, H. N. Doan, and L. Liang, "Environmental health risk assessment of heavy metal exposure among children living in an informal e-waste processing village in Viet Nam," *Science of the Total Environment*, vol. 763, Apr. 2021, doi: 10.1016/j.scitotenv.2020.142982.

[13] M. Andreassen, C. Rudén, and M. Ågerstrand, "Mapping chemicals across EU's legal frameworks towards a 'one substance, one assessment' approach," *Environment International*, vol. 199, May 2025, doi: 10.1016/j.envint.2025.109460.

[14] M. Pereira, D. S. Macmillan, C. Willett, and T. Seidle, "REACHing for solutions: Essential revisions to the EU chemicals regulation to modernise safety assessment," *Regulatory Toxicology and Pharmacology*, vol. 136, Dec. 2022, doi: 10.1016/j.yrtph.2022.105278.

[15] A. Reihlen, M. Goulart, T. Santos, and M. Warhurst, *Waiting for REACH: the negative impacts of delaying reform of EU chemical laws*, Brussels, Belgium: European Environmental Bureau and CHEM Trust, Mar. 2023.

[16] M. Tahmid, S. Dey, and S. R. Syeda, "Mapping human vulnerability and risk due to chemical accidents," *Journal of Loss Prevention in the Process Industries*, vol. 68, 2020, doi: 10.1016/j.jlp.2020.104289.

[17] P. V. Yemelin, S. S. Kudryavtsev, and N. K. Yemelina, "The methodological approach to environmental risk assessment from man-made emergencies at chemically hazardous sites," *Environmental Engineering Research*, vol. 26, no. 4, pp. 200380–200386, Sep. 2021, doi: 10.4491/eer.2020.386.

[18] L. Liu, Q. Wu, S. Li, Y. Li, and T. Fan, "Risk assessment of hazmat road transportation considering environmental risk under time-varying conditions," *International Journal of Environmental Research and Public Health*, vol. 18, no. 18, 2021, doi: 10.3390/ijerph18189780.

[19] S. Kim *et al.*, "PubChem in 2021: new data content and improved web interfaces," *Nucleic Acids Research*, vol. 49, no. D1, pp. D1388–D1395, 2021, doi: 10.1093/nar/gkaa971.

[20] L. W. Stanek *et al.*, "Environmental public health research at the U.S. Environmental Protection Agency: a blueprint for exposure science in a connected world," *Journal of Exposure Science and Environmental Epidemiology*, vol. 35, no. 4, pp. 539–547, Jul. 2025, doi: 10.1038/s41370-024-00720-8.

[21] D. Michaels and G. R. Wagner, "OSHA injury data: an opportunity for improving work injury prevention," *American Journal of Public Health*, vol. 115, no. 4, pp. 588–595, Apr. 2025, doi: 10.2105/AJPH.2024.307934.

[22] S. Chaiprakarn, C. Sakulthaew, M. Ratcha, and P. Saengseedam, "Occupational chemical exposure and risk assessment among workers in power plant process, Rayong Province, Thailand," *Indonesian Journal of Occupational Safety and Health*, vol. 14, no. 1, pp. 89–97, Apr. 2025, doi: 10.20473/ijosh.v14i1.2025.89-97.

[23] D. J. C. Rodriguez, H. Shi, M. Vitale, M. Demichela, and A. A. Barresi, "Assessing the major industrial accident potential based on dangerous substance criteria: a framework for Seveso and non-Seveso facilities," *Chemical Engineering Transactions*, vol. 116, pp. 409–414, 2025, doi: 10.3303/CET25116069.

[24] O. Sanvido *et al.*, "Quantitative risk assessment of skin sensitising pesticides: clinical and toxicological considerations," *Regulatory Toxicology and Pharmacology*, vol. 144, Oct. 2023, doi: 10.1016/j.yrtph.2023.105493.

[25] Department of Industrial Works, "Announcement of the department of industrial works regarding the manual for the storage of chemicals and hazardous materials, B.E. 2550 (2007) (in Thai)," *Royal Gazette Thailand*, 2021, Accessed: Aug. 23, 2025. [Online]. Available: https://www.diw.go.th/webdiw/wp-content/uploads/2021/07/law-haz-anndiw-22012551.pdf

[26] Department of Industrial Works, "Regulation of the Department of Industrial Works re: criteria for hazard identification, risk assessment, and risk management planning, B.E. 2543 (2000) (in Thai)," *Royal Gazette Thailand*, 2021. Accessed: Aug. 23, 2025. [Online]. Available: https://www.diw.go.th/webdiw/wp-content/uploads/2021/07/law-fac-saft-17112543.pdf

[27] C. Wang, S. Huang, N. Lassi, and X. Zhang, "A decade of China's health silk road: policy review for global health governance and SDG partnerships," *Frontiers in Public Health*, vol. 13, Sep. 2025, doi: 10.3389/fpubh.2025.1676960.
[28] Y. Liu, C. S. V. Arachchige, J. Xue, C. K. Odoh, and R. Naidu, "Navigating the crossroads risk assessment in the world of industrial chemicals," in *The Old and New Persistent Organic Pollutants: Sources, Risks, Regulations, and Remediation*, Boca Raton: CRC Press, 2025, pp. 77–105, doi: 10.1201/9781003530466-5.
[29] G. Shavalieva, P. Kazepidis, A. I. Papadopoulos, P. Seferlis, and S. Papadokonstantakis, "Environmental, health and safety assessment of post-combustion CO_2 capture processes with phase-change solvents," *Sustainable Production and Consumption*, vol. 25, pp. 60–76, Jan. 2021, doi: 10.1016/j.spc.2020.07.015.
[30] M. Amoadu, E. W. Ansah, and J. O. Sarfo, "Influence of psychosocial safety climate on occupational health and safety: a scoping review," *BMC Public Health*, vol. 23, no. 1, p. 1344, 2023, doi: 10.1186/s12889-023-16246-x.
[31] A. Cohen, M. J. Colligan, R. Sinclair, J. Newman, and R. Schuler, *Assessing occupational safety and health training: a literature review*, Cincinnati, Ohio: National Institutes of Health, 1998.
[32] J. Oakman, V. Weale, N. Kinsman, H. Nguyen, and R. Stuckey, "Workplace physical and psychosocial hazards: a systematic review of evidence informed hazard identification tools," *Applied Ergonomics*, vol. 100, Apr. 2022, doi: 10.1016/j.apergo.2021.103614.
[33] M. Yazdi *et al.*, "Fault tree analysis improvements: a bibliometric analysis and literature review," *Quality and Reliability Engineering International*, vol. 39, no. 5, pp. 1639–1659, Jul. 2023, doi: 10.1002/qre.3271.
[34] X. Huang, Y. Wen, F. Zhang, H. Li, Z. Sui, and X. Cheng, "Accident analysis of waterway dangerous goods transport: building an evolution network with text knowledge extraction," *Ocean Engineering*, vol. 318, Feb. 2025, doi: 10.1016/j.oceaneng.2024.120176.
[35] Department of Internal Trade, "Analytic hierarchy process (AHP) (in Thai)," Ministry of Commerce, Thailand, 2019, Accessed: Aug. 23, 2025. [Online]. Available: https://www.dti.or.th/download/150319174753_3ahp4.pdf
[36] C. Nys, E. Middleton, E. Garman, C. Schlekat, P. V. Sprang, and K. D. Schamphelaere, "Development of a bioavailability-based acute effects assessment method for nickel," *Environmental Toxicology and Chemistry*, vol. 44, no. 3, pp. 841–855, Mar. 2025, doi: 10.1093/etojnl/vgae071.
[37] L. P. Burkhard, "Evaluation of published bioconcentration factor (BCF) and bioaccumulation factor (BAF) data for per- and polyfluoroalkyl substances across aquatic species," *Environmental Toxicology and Chemistry*, vol. 40, no. 6, pp. 1530–1543, Feb. 2021, doi: 10.1002/etc.5010.
[38] M. Nendza, V. Kosfeld, and C. Schlechtriem, "Consolidated octanol/water partition coefficients: combining multiple estimates from different methods to reduce uncertainties in log K_{OW}," *Environmental Sciences Europe*, vol. 37, no. 1, Mar. 2025, doi: 10.1186/s12302-025-01072-2.
[39] Y. Chernysh *et al.*, "Risk assessment as a tool to improve water resource management," *Water Resources Management*, vol. 39, no. 1, pp. 47–63, Jan. 2025, doi: 10.1007/s11269-024-03982-x.
[40] A. Bearth *et al.*, "New approach methodologies in human health risk assessment across European regulatory frameworks: status quo, barriers and drivers for regulatory acceptance and use," *Environment International*, vol. 196, Feb. 2025, doi: 10.1016/j.envint.2025.109279.
[41] P. A. White, A. S. Long, and G. E. Johnson, "Quantitative interpretation of genetic toxicity dose-response data for risk assessment and regulatory decision-making: current status and emerging priorities," *Environmental and Molecular Mutagenesis*, vol. 61, no. 1, pp. 66–83, Jan. 2020, doi: 10.1002/em.22351.
[42] S. More *et al.*, "Statement on the derivation of health-based guidance values (HBGVs) for regulated products that are also nutrients," *EFSA Journal*, vol. 19, no. 3, 2021, doi: 10.2903/j.efsa.2021.6479.
[43] J. A. Zarn, U. A. Zürcher, and H. C. Geiser, "Toxic responses induced at high doses may affect benchmark doses," *Dose-Response*, vol. 18, no. 2, 2020, doi: 10.1177/1559325820919605.
[44] F. Alvarez *et al.*, "Peer review of the pesticide risk assessment of the active substance sheep fat," *EFSA Journal*, vol. 20, no. 1, 2022, doi: 10.2903/j.efsa.2022.7073.
[45] M. Li, R. Han, J. Li, W. Wu, and J. Gu, "Research progress in acute oral toxicity testing methods," *International Journal of Biology and Life Sciences*, vol. 6, no. 1, pp. 19–22, 2024, doi: 10.54097/nv9van65.
[46] J. Hamm *et al.*, "Performance of the GHS mixtures equation for predicting acute oral toxicity," *Regulatory Toxicology and Pharmacology*, vol. 125, 2021, doi: 10.1016/j.yrtph.2021.105007.
[47] H. Stratmann, L. M.-Hock, S. Tangermann, and R. A. Corley, "Refinement of the acute inhalation limit test for inert, nano-sized dusts by an in silico dosimetry-based evaluation: case study for the dissolution of a regulatory dilemma," *Frontiers in Toxicology*, vol. 5, 2023, doi: 10.3389/ftox.2023.1258861.
[48] M. Ahmad *et al.*, "Fine particulate matter from brick kilns site and roadside in Lahore, Pakistan: Insight into chemical composition, oxidative potential, and health risk assessment," *Heliyon*, vol. 10, no. 4, Feb. 2024, doi: 10.1016/j.heliyon.2024.e25884.
[49] J. Juwari, R. P. Anugraha, M. Zanata, N. A. Leksono, M. D. Hamid, and T. Cahyono, "Quantitative risk assessment and risk reduction of worst-case accident scenario at fuel storage terminal," *Journal of Loss Prevention in the Process Industries*, vol. 88, 2024, doi: 10.1016/j.jlp.2024.105272.
[50] L. Jiang, D. Zeinali, K. S. Arsava, and D. O. Snersrud, "The impact of water-based fire suppression systems on combustion products," *Fire Technology*, vol. 61, no. 4, pp. 2441–2465, 2025, doi: 10.1007/s10694-024-01689-4.
[51] M. S. A. Rahim, G. Reniers, M. Yang, and S. Bajpai, "Risk assessment methods for process safety, process security and resilience in the chemical process industry: a thorough literature review," *Journal of Loss Prevention in the Process Industries*, vol. 88, Apr. 2024, doi: 10.1016/j.jlp.2024.105274.
[52] S. V. Esmaeili, A. Alboghobeish, H. Yazdani, A. G. Koozekonan, and M. Pouyakian, "Optimizing in-store warehouse safety: a DEMATEL approach to comprehensive risk assessment," *PLoS ONE*, vol. 20, no. 2, Feb. 2025, doi: 10.1371/journal.pone.0317787.
[53] W. Jiang, W. Han, J. Zhou, and Z. Huang, "Analysis of human factors relationship in hazardous chemical storage accidents," *International Journal of Environmental Research and Public Health*, vol. 17, no. 17, pp. 1–14, 2020, doi: 10.3390/ijerph17176217.
[54] J. M.-Tejon, M. J.-Partearroyo, and D. B.-Osorio, "Integrated security management model: a proposal applied to organisational resilience," *Security Journal*, vol. 37, no. 2, pp. 375–398, Jun. 2024, doi: 10.1057/s41284-023-00381-6.
[55] W. Zhou, M. Li, and V. Achal, "A comprehensive review on environmental and human health impacts of chemical pesticide usage," *Emerging Contaminants*, vol. 11, no. 1, Mar. 2025, doi: 10.1016/j.emcon.2024.100410.

[56] D. O. Badea, D. C. Darabont, I. Ivan, V. Ciocîrlea, R. A. Stepa, and O. R. Chivu, "Workers' exposure to chemical risk in small and medium-sized enterprises: assessment methodology and field study," *Sustainability*, vol. 16, no. 15, 2024, doi: 10.3390/su16156308.
[57] P. S. Nishmitha, K. A. Akhilghosh, V. P. Aiswriya, A. Ramesh, M. Muthuchamy, and A. Muthukumar, "Understanding emerging contaminants in water and wastewater: A comprehensive review on detection, impacts, and solutions," *Journal of Hazardous Materials Advances*, vol. 18, May 2025, doi: 10.1016/j.hazadv.2025.100755.
[58] C. V. Rider, "Mixture math: deciding what to add in a cumulative risk assessment," *Current Opinion in Toxicology*, vol. 31, Sep. 2022, doi: 10.1016/j.cotox.2022.100358.
[59] Y. He, J. He, and N. Wen, "The challenges of IoT-based applications in high-risk environments, health and safety industries in the Industry 4.0 era using decision-making approach," *Journal of Innovation and Knowledge*, vol. 8, no. 2, Apr. 2023, doi: 10.1016/j.jik.2023.100347.
[60] S. S. Shetty *et al.*, "Environmental pollutants and their effects on human health," *Heliyon*, vol. 9, no. 9, Sep. 2023, doi: 10.1016/j.heliyon.2023.e19496.
[61] L. Appolloni, D. Valeri, and D. D'Alessandro, "Knowledge on indoor air quality (K-IAQ): development and evaluation of a questionnaire through the application of item response theory," *Atmosphere*, vol. 16, no. 10, Oct. 2025, doi: 10.3390/atmos16101163.
[62] C. Qi, Q. Zou, Y. Cao, and M. Ma, "Hazardous chemical laboratory fire risk assessment based on ANP and 3D risk matrix," *Fire*, vol. 7, no. 8, Aug. 2024, doi: 10.3390/fire7080287.
[63] J. Y. Jung, S. H. Park, J. E. Moon, J. H. Yoon, S. W. Yoon, and C. M. Lee, "Aggregate risk assessment for multi-route exposure to hazardous chemicals caused by chemical accidents, with a focus on toluene," *Asian Journal of Atmospheric Environment*, vol. 18, no. 1, Aug. 2024, doi: 10.1007/s44273-024-00039-8.
[64] S. Pu, J. P. McCord, J. Bangma, and J. R. Sobus, "Establishing performance metrics for quantitative non-targeted analysis: a demonstration using per- and polyfluoroalkyl substances," *Analytical and Bioanalytical Chemistry*, vol. 416, no. 5, pp. 1249–1267, 2024, doi: 10.1007/s00216-023-05117-4.
[65] X. Trier, S. P. J. V.-Leeuwen, G. Brambilla, R. Weber, and T. F. Webster, "The critical role of commercial analytical reference standards in the control of chemical risks: the case of PFAS and ways forward," *Environmental Health Perspectives*, vol. 133, no. 1, Jan. 2025, doi: 10.1289/EHP12331.
[66] F. Borchert, A. Beronius, and M. Ågerstrand, "Characterisation and analysis of key studies used to restrict substances under REACH," *Environmental Sciences Europe*, vol. 34, no. 1, 2022, doi: 10.1186/s12302-022-00662-8.
[67] T. Nakyai, S. Phatrabuddha, P. Homsri, and N. Phatrabuddha, "Risk assessment of ammonia leakage by fault tree analysis: case study in the ice manufacture, Chonburi province," *F1000Research*, vol. 14, Feb. 2025, doi: 10.12688/f1000research.159905.1.
[68] W. Galert and E. Hassold, "Environmental risk assessment of technical mixtures under the european registration, evaluation, authorisation and restriction of chemicals—a regulatory perspective," *Integrated Environmental Assessment and Management*, vol. 17, no. 3, pp. 498–506, Jan. 2021, doi: 10.1002/ieam.4393.
[69] M. T. Miah, S. E.-Gally, A. Dancs, and M. F.-Farkas, "A systematic review of industry 4.0 technology on workforce employability and skills: driving success factors and challenges in South Asia," *Economies*, vol. 12, no. 2, 2024, doi: 10.3390/economies12020035.
[70] A. A. Artamonov, L. M. Bogdanova, S. Y. Nagibin, D. I. Loskutov, and A. S. Chemakin, "Mathematical model of chemical process prediction for industrial safety risk assessment," *Procedia Computer Science*, vol. 190, pp. 107–114, 2021, doi: 10.1016/j.procs.2021.06.013.
[71] D. Krewski *et al.*, "Development of an evidence-based risk assessment framework," *Altex*, vol. 39, no. 4, pp. 667–693, 2022, doi: 10.14573/altex.2004041.
[72] P. V. Yemelin, S. S. Kudryavtsev, and N. K. Yemelina, "The methodological approach to environmental risk assessment from man-made emergencies at chemically hazardous sites," *Environmental Engineering Research*, vol. 26, no. 4, Sep. 2020, doi: 10.4491/eer.2020.386.
[73] A. Mazzi, "Environmental and safety risk assessment for sustainable circular production: case study in plastic processing for fashion products," *Heliyon*, vol. 9, no. 11, Nov. 2023, doi: 10.1016/j.heliyon.2023.e21352.

APPENDIX

Table 3. EHS risk assessment research trends during the past five years, 2020-2025

Ref.	EHS risk assessment				Contributions/findings
	Environment	Health	Safety	Research direction	
[1]	✓	✓		✓	The findings reveal chemical mismanagement, delayed emergency response, and severe risks to community health and the environment, resulting in significant adverse consequences.
[3]			✓	✓	Effective hazard assessment methods and clear communication significantly improve safety awareness and understanding among non-expert personnel.
[4]			✓		The findings reveal that systematic chemical risk assessments enhance safety culture, reduce the likelihood of accidents, and improve overall environmental performance.
[6]	✓	✓	✓	✓	Analysis indicates that uneven global adoption of the GHS hinders consistent EHS hazard communication and constrains progress toward improved international chemical safety.
[10]			✓	✓	The study finds that factory inspection programs improve risk assessment accuracy, strengthen regulatory compliance, and enhance overall industrial safety performance.
[13]	✓			✓	This study proposes a methodological framework for assessing environmental risks arising from industrial accidents at chemical storage sites.

Table 3. EHS risk assessment research trends during the past five years, 2020-2025 *(continued)*

Ref.	EHS risk assessment				Contributions/findings
	Environment	Health	Safety	Research direction	
[15]		✓			The paper outlines the U.S. Environmental Protection Agency (EPA) strategy to integrate advanced exposure science and data systems to strengthen risk assessment capabilities and enhance public health protection.
[16]		✓			The study develops quantitative methods to assess skin sensitization risks associated with pesticides by integrating clinical evidence with toxicological data.
[23]			✓	✓	The findings demonstrate the application of Bayesian networks to assess risks associated with hazardous material road accidents across pre-incident, incident, and post-incident phases.
[24]	✓	✓	✓		The study evaluates EHS risks associated with post-combustion CO_2 capture using phase-change solvent technologies.
[3]	✓	✓	✓	✓	The case study demonstrates that integrating health, safety, and EMSs enhances organizational performance while strengthening regulatory compliance.
[25]		✓	✓	✓	The report emphasizes that effective occupational safety and health training enhances worker knowledge, reduces accident rates, and significantly improves overall workplace safety.
[27]	✓	✓	✓	✓	The paper reviews and analyzes recent improvements in EHS fault tree analysis, highlighting key methodological developments and emerging trends in risk assessment practice.
[29]			✓		The study analyzes accidents involving hazardous goods on waterways by applying text-based knowledge extraction methods to map accident evolution networks.
[34]		✓		✓	The study reveals new methodologies in European health risk assessment, identifying key barriers and drivers influencing regulatory adoption.
[35]		✓		✓	The study evaluates quantitative approaches for interpreting genetic toxicity dose-response data to support risk assessment processes and inform regulatory decision-making.
[38]	✓	✓		✓	The chapter outlines methods for assessing human and ecological exposure, providing practical guidance to support risk evaluation and informed risk management decisions.
[43]	✓	✓	✓		The study develops a dynamic risk assessment framework for chemical industrial parks by integrating Bayesian networks with fuzzy fault tree analysis to enhance the evaluation of complex and evolving risk scenarios.
[44]			✓	✓	The study proposes a model for estimating fire protection and emergency response resource requirements to ensure the safe management of hazardous chemical storage facilities.
[45]			✓	✓	The review evaluates risk assessment methods applied in the chemical industry, with a particular focus on improving safety, security, and system resilience.
[46]			✓		The study reveals a decision-making trial and evaluation laboratory (DEMATEL)-based approach for optimizing chemical warehouse safety through a comprehensive and systematic risk assessment process.
[49]	✓	✓		✓	The study reveals the environmental and human health impacts of chemical pesticides, highlighting key risks, exposure pathways, and potential mitigation strategies to reduce adverse effects.
[50]			✓	✓	The review examines approaches to chemical safety and security risk management, highlighting key strategies, regulatory frameworks, and best practices for effective hazard identification, mitigation, and prevention.
[53]			✓	✓	The paper introduces the risk analysis screening tool, presenting an overview of its application for preliminary hazard identification and initial process safety evaluation.
[55]	✓	✓	✓		The study explores the challenges associated with implementing internet of things (IoT) applications in high-risk health and safety industries, employing decision-making approaches to evaluate technological, organizational, and operational constraints.
[59]			✓		The study optimizes shelter locations and evacuation routes to enhance safety and emergency response effectiveness during gas leakage accidents in chemical industrial parks.
[60]			✓	✓	The study conducts an aggregate risk assessment of multi-route exposure to hazardous chemicals, with a specific focus on toluene exposure resulting from chemical accidents.
[64]	✓	✓		✓	The study reveals the importance of commercial analytical reference standards for effective chemical risk control, illustrated through case studies involving per- and polyfluoroalkyl substances (PFAS).
[65]	✓			✓	The paper reviews environmental risk assessment approaches for chemical mixtures under the EU REACH regulation, highlighting key regulatory methodologies, implementation challenges, and gaps in managing combined chemical exposures.

Table 3. EHS risk assessment research trends during the past five years, 2020-2025 *(continued)*

Ref.	EHS risk assessment				Contributions/findings
	Environment	Health	Safety	Research direction	
[66]		✓			The study assesses occupational chemical exposure and associated health risks among power plant workers in Rayong Province, Thailand.
[70]			✓	✓	The study develops a mathematical modeling approach to predict chemical process behavior, supporting more accurate and proactive industrial safety risk assessment.
[72]	✓			✓	The study proposes a methodological approach for assessing environmental risks arising from man-made emergencies at chemically hazardous sites.
[73]	✓		✓		The study evaluates environmental and safety risks associated with sustainable circular plastic production, highlighting key mitigation strategies to reduce adverse impacts and improve process safety.

BIOGRAPHIES OF AUTHORS

Hengheng Jarunongkran is a professional engineer in the Department of Industrial Works. He received his B.Eng. in Chemical Engineering from Kasetsart University in 2006 and M.Eng. in Chemical Engineering from Mahanakorn University of Technology in 2009. He is currently a Ph.D. candidate in Sustainable Industrial Management Engineering in the Faculty of Engineering at Rajamangala University of Technology Phra Nakhon. His research interests include risk assessment for hazardous chemicals, catalyst engineering, and sustainable energy. He can be contacted at email: hengheng-j@rmutp.ac.th.

Therdpong Daengsi is an associate professor in the Faculty of Engineering at Rajamangala University of Technology Phra Nakhon. He received his B.Eng. in Electrical Engineering from King Mongkut's University of Technology North Bangkok in 1997. He later obtained an M.Sc. in Information and Communication Technology from Assumption University in 2008. In 2012, he earned a Ph.D. in Information Technology from King Mongkut's University of Technology North Bangkok. With 19 years of experience in the telecommunications sector, he also worked as an independent academic for a short period before becoming a lecturer. His research interests include quality of service/quality of experience, mobile networks, cybersecurity, and sustainability. He can be contacted at email: therdpong.d@rmutp.ac.th.