

Rainfall-Related Safety Hazards on Construction Sites: A Multidimensional Assessment of Practitioner Perceptions in Malaysia

Mohamed Nur Akmal Radzuan¹, Idris Othman², Murshamshul Kamariah Musa³, Siti Haslina Hussin⁴,
Mohamad Zain Hashim^{1*}

¹Civil Engineering Studies, College of Engineering, Universiti Teknologi MARA Cawangan Pulau Pinang, Pematang Pauh Campus, 13500 Pulau Pinang, Malaysia

²Department of Civil & Environmental Engineering, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak, Malaysia

³Faculty of Law & International Relations, Universiti Sultan Zainal Abidin, Kampus Gong Badak, 21300 Kuala Terengganu, Terengganu

⁴Fakulti Pendidikan, Bahasa Dan Komunikasi, Universiti Malaysia Sarawak, Kota Samarahan 94300, Sarawak, Malaysia

*Corresponding Author

DOI: <https://doi.org/10.47772/IJRISS.2026.100900177>

Received: 21 September 2026; Accepted: 26 September 2026; Published: 05 October 2026

ABSTRACT

Rainfall can intensify existing construction hazards by altering site conditions, equipment operation, worker performance, and coordination. However, rainfall-related construction safety has received less empirical attention than weather-related productivity and delay, particularly in tropical environments such as Malaysia. This study aimed to identify and prioritise rainfall-related safety hazards, determine their underlying dimensions, and examine whether hazard perceptions differ according to selected practitioner characteristics. A quantitative cross-sectional survey was conducted among 128 construction practitioners in Malaysia using ten rainfall-related safety-hazard items measured on a five-point Likert scale. Descriptive statistics, the Friedman test, exploratory factor analysis using Principal Axis Factoring with Direct Oblimin rotation, reliability analysis, and group-comparison tests were applied. All ten hazards recorded relatively high mean scores, ranging from 3.95 to 4.16. However, the Friedman test showed no statistically significant differences among the hazard ratings, $\chi^2(9) = 4.961$, $p = .838$, indicating that practitioners generally perceived the hazards as similarly important. Exploratory factor analysis identified two related dimensions: Site Exposure and Physical Hazards (SEPH) and Operational and Human-Factor Hazards (OHFH). Both dimensions demonstrated strong internal consistency, with Cronbach's alpha values of .905 and .875, respectively. Gender was not associated with significant differences in either dimension. Age showed an overall difference for OHFH but not SEPH, while work experience showed significant overall differences in both dimensions; however, adjusted post-hoc comparisons did not identify significant differences between specific groups. The findings suggest that rainfall-related construction safety should be managed through an integrated approach addressing both physical site exposure and operational and human-factor risks.

Keywords: Rainfall-related hazards; construction safety; rainy conditions; exploratory factor analysis; site exposure; human factors; Malaysia

INTRODUCTION

Construction remains a safety-critical industry because workers are routinely exposed to changing work environments, temporary structures, heavy equipment, electrical installations, work at height, uneven surfaces, and simultaneous operations involving multiple trades. These characteristics create combinations of hazards that

can change rapidly as a project progresses. Falls remain particularly important; the U.S. National Institute for Occupational Safety and Health (NIOSH) identifies falls as the leading work-related cause of death in construction, while struck-by incidents and electrical hazards also continue to represent major sources of serious injury and fatality. Construction safety therefore cannot be understood solely in terms of worker behaviour or compliance with safety procedures; environmental and site conditions can also alter the probability and severity of hazardous events (NIOSH, 2026). Weather is one such environmental factor. Construction workers frequently perform tasks outdoors, meaning that their exposure to workplace hazards occurs simultaneously with exposure to rainfall, temperature, wind, humidity, and other climatic conditions. A review of 170 studies examining climate change and occupational health and safety concluded that weather conditions, including rain, can increase risks of occupational injury, accidents, disease, and death. Within construction specifically, weather-related research has traditionally concentrated more heavily on productivity and delay than on worker safety. Al Refaie et al., (2021), for example, found that the construction-weather literature contains substantial work on productivity management, seasons, weather factors, and worker conditions, but identified health and safety as only one component within a broader field dominated by performance-oriented research. This imbalance is significant because an activity may remain technically possible during rain while becoming substantially more hazardous to perform.

Rainfall can affect construction safety through several mechanisms rather than through a single direct pathway. Wet surfaces may increase the potential for slips and falls, saturated soils may reduce ground stability, rainfall and mist may impair visibility around workers and moving equipment, and water may interact with temporary electrical systems or damaged equipment. Working at height can become more hazardous when access platforms, ladders, scaffolds, roofs, and structural surfaces become wet. Electrical hazards are particularly relevant because accident research has identified wet environments as one of the environmental conditions associated with fatal electrical incidents in construction. Chi et al., (2009), in an analysis of 255 construction-related electrical fatalities, explicitly considered wet working areas among the environmental factors contributing to electrocution patterns. Similarly, NIOSH identifies electrocution as one of the persistent major construction hazards and notes that electrical injuries can themselves lead to secondary falls from height. Thus, rainfall does not necessarily create entirely new hazards; rather, it can amplify hazards already embedded within construction activities. Empirical accident evidence supports the need to treat rainfall as a safety variable. Liao & Perng, (2008) analysed occupational injury reports from Taiwan's construction industry and incorporated weather-related factors into their data-mining model. Their findings indicated that rain was significantly associated with patterns of construction fatalities, leading the authors to recommend that inspection and prevention strategies account for both construction type and environmental conditions. Seasonal accident analysis has similarly identified wet and unpredictable weather as relevant to fall and electrical risks in construction. These studies are important because they move beyond treating weather simply as a source of lost working time. Nevertheless, much of this evidence originates outside tropical Southeast Asia, and accident-record studies generally establish associations after incidents have occurred rather than identifying how practitioners prioritise different rainfall-related hazards before an accident takes place.

This distinction is especially relevant in Malaysia. Construction already represents a significant occupational safety concern nationally. The Department of Occupational Safety and Health Malaysia (DOSH) reported 67 fatal injuries in the construction sector in 2023, making construction the sector with the highest contribution to fatal occupational injuries that year. Malaysia has subsequently strengthened construction safety governance through the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024, which came into force on 1 June 2024 and establish safety and health responsibilities for key project stakeholders, including clients, designers, and builders (DOSM, 2024). The regulatory emphasis on proactive risk management reinforces the importance of identifying environmental conditions that may alter construction hazards before incidents occur. Existing Malaysian construction-safety research has, however, largely examined broad accident causation rather than rainfall-specific hazard profiles. Manzoor et al., (2021), for example, evaluated 62 critical safety factors associated with Malaysian high-rise construction and identified falls from roofs or floors and inadequate fall protection among the most critical accident-related factors. Such findings establish the importance of conventional construction hazards, particularly working at height, but do not establish how these hazards change when rainfall affects walking surfaces, visibility, equipment operation,

electrical conditions, or worker concentration. A hazard such as working at height may therefore have a different risk profile under dry and wet conditions even though the underlying task remains unchanged.

Recent climate-resilience research further highlights this limitation. Mohd Azmi & Misnan, (2026) reviewed research integrating design safety with climate-change resilience in construction and found only eight studies satisfying their inclusion criteria from an initial 98 records. Their synthesis identified a particular shortage of worker-focused safety research addressing climate stressors and argued for stronger integration between safety-by-design principles and climate resilience, especially within the Malaysian construction context. Similarly, recent international research has argued that climate-related protection for construction workers requires coordinated organisational measures and weather-contingent work planning rather than fragmented responses to individual environmental hazards. Collectively, these studies indicate that climate and construction safety are increasingly being connected conceptually, but empirical evidence on rainfall-specific safety hazards remains comparatively limited. Another limitation of existing research concerns the way hazards are commonly assessed. Construction-safety surveys frequently rank individual factors according to mean scores or importance indices. Although such ranking identifies which hazards practitioners regard as most serious, it does not establish whether apparently different hazards represent broader underlying categories. Rain-related slips, ground instability, flooding, machinery difficulties, electrical exposure, working-at-height risks, impaired concentration, inappropriate protective equipment, and communication difficulties may not operate as ten completely independent problems. Some may represent physical or environmental hazards, others equipment and electrical hazards, and others human or organisational safety conditions. Determining whether such dimensions exist empirically can provide a more useful basis for safety planning than a simple list of ranked hazards.

Accordingly, the present study examines rainfall-related safety hazards on Malaysian construction sites from the perspective of construction practitioners. Specifically, the study aims (1) to identify and prioritise the rainfall-related hazards perceived to affect construction-site safety; (2) to determine whether the assessed hazards form meaningful underlying safety-risk dimensions; and (3) to examine whether perceptions of rainfall-related hazards differ according to selected practitioner characteristics. By combining descriptive prioritisation with exploratory factor analysis and practitioner-group comparisons, the study moves beyond the conventional ranking of isolated safety factors. Its contribution lies in developing a more structured understanding of how rainfall can interact with physical, equipment-related, environmental, and human aspects of construction safety in a tropical environment. Such evidence can support more targeted rainy-weather risk assessments, work planning, inspection priorities, and preventive safety measures on Malaysian construction sites.

LITERATURE REVIEW

Construction safety as a multidimensional problem

Construction safety is shaped by the interaction of workers, tasks, equipment, the physical work environment, management systems, and wider organisational conditions. Consequently, construction accidents should not be interpreted solely as the result of individual unsafe behaviour. In a review of 90 construction-safety studies, Mohammadi et al., (2018) identified 113 safety-related subfactors distributed across 13 major categories and concluded that safety performance is influenced by interactions between factors operating at different organisational and project levels. Similarly, Jaafar et al., (2018), reviewing construction occupational safety and health with reference to Malaysia, grouped accident-related influences into human, worksite, management, and external elements. These perspectives are important because environmental conditions such as rainfall do not operate independently; rather, they modify the conditions under which established construction hazards are encountered. Nevertheless, a substantial proportion of construction-safety research has concentrated on familiar accident categories such as falls, electrocution, struck-by incidents, equipment interactions, poor supervision, inadequate training, and unsafe work procedures. For example, Malaysian research on high-rise projects identified falls from roofs or floors without adequate fall protection as one of the most critical accident factors. More recent Malaysian research in downstream oil and gas construction identified inadequate safety training, insufficient safety procedures, and inadequate supervision as significant contributors to accidents. Although these studies provide valuable evidence regarding construction accident causation, environmental conditions tend to appear as one element among many rather than as the principal analytical focus. This distinction creates an important research issue. The question is not simply whether rainfall constitutes another hazard to be added

to an existing list. Rainfall may instead change the severity, probability, or interaction of hazards that already exist. A walking surface that is manageable under dry conditions may become hazardous when wet; working at height may become more difficult when footing is slippery; temporary electrical equipment may be more problematic in wet environments; and equipment movement may become less predictable when visibility and ground stability deteriorate. Conceptualising rainfall as a hazard amplifier therefore provides a more useful framework than treating rainfall as an isolated safety factor.

Weather exposure and occupational safety

Growing occupational-health literature supports the wider proposition that climatic conditions can alter workplace safety. Ferrari et al., (2022), in a systematic mapping of 170 studies, found that weather-related exposures including rain, heat, and air pollution can increase occupational risks involving illness, injury, accidents, and mortality. However, the authors also found that temperature-related exposure dominated the research literature. This imbalance is important: although climate-related occupational research is expanding, rainfall-specific mechanisms remain considerably less developed than heat-related effects. The same tendency is visible in research specifically involving construction workers. Baek & Choi, (2026) found that climate-related risks to construction workers involve interactions between environmental exposure, worker health, organisational constraints, scheduling, education, and protective measures. Their practitioner-informed study emphasised weather-contingent scheduling and coordinated organisational protection rather than isolated responses to individual hazards. However, their framework focused principally on climate factors such as heat waves, humidity, cold waves, and air quality. Thus, although contemporary research increasingly recognises the need to integrate climate conditions into construction safety management, rainfall remains comparatively underdeveloped as a distinct empirical safety domain. Accident-based research provides more direct evidence. Liao & Perng, (2008) analysed 309 fatal occupational injuries in Taiwan's construction industry while explicitly incorporating weather conditions into the analysis. Their findings showed that rainfall was meaningfully associated with patterns of fatal construction injuries and that inspection strategies should consider both project characteristics and environmental conditions. This study is particularly relevant because it demonstrates that weather should not be treated merely as background information in accident investigations. At the same time, accident-database studies are necessarily retrospective: they reveal conditions associated with accidents that have already occurred but provide less information about how current practitioners perceive and prioritise rainfall-related hazards before an incident occurs. The methodological contrast is therefore important. Accident databases offer stronger evidence of actual adverse outcomes, but may contain limited information on site conditions that did not culminate in a reportable incident. Practitioner surveys cannot establish actual accident causation, yet they can identify recurrent hazards, near-miss conditions, and operational concerns that may not appear in formal accident records. The two approaches should thus be viewed as complementary rather than competing.

Wet surfaces, slips, falls, and ground instability

Slips and falls represent one of the most direct mechanisms through which rainfall may affect construction safety. Lipscomb et al., (2006), analysing injuries during construction of Denver International Airport, found that slips and trips accounted for approximately 18% of recorded injuries and 25% of workers' compensation payments. Slips were involved in most same-level falls and also contributed to falls from height. Importantly, the authors identified environmental conditions—including walking and working surfaces, terrain, and weather—as prominent contributing factors. This evidence is particularly relevant to rainfall because precipitation may contaminate walking and working surfaces with water, mud, or other material and reduce available traction. Yet the findings of Lipscomb et al., (2006) also illustrate why rainfall should not be equated automatically with slipping. Their analysis identified a combination of environmental, task, and movement-related influences, meaning that wet conditions interact with factors such as surface condition, carrying materials, access routes, stairs, ladders, and changing site geometry. Thus, rainfall may increase risk, but the resulting hazard is mediated by the characteristics of the construction environment. Falls from height require particular attention because the consequences can be severe. Construction-safety research consistently recognises falls from height as a major accident category, and Malaysian evidence from high-rise construction has identified unprotected work at roof and floor edges as a critical safety factor. A review of fall-prevention technologies likewise described falling from height as a major source of construction injury and death. When combined with rainfall, the hazard may

involve wet access systems, slippery scaffolding or structural surfaces, reduced visual clarity, and difficulties maintaining stable footing. The literature therefore supports assessing rainfall-related working-at-height risk as a distinct construction-safety concern rather than assuming that conventional fall-protection measures alone capture the additional environmental influence. Ground instability represents a related but different pathway. Rainfall can affect soil and temporary ground surfaces, particularly on projects involving excavation, earthworks, unpaved access, or incomplete drainage. Although much of the construction literature on rainfall and soil conditions has focused on productivity rather than accidents, the safety implication is clear: degraded ground conditions can alter the stability and mobility of workers, plant, temporary works, and access routes. Consequently, items assessing slippery or unstable soil conditions should not necessarily be treated as equivalent to same-level slipping hazards. One concerns surface traction, while the other may involve broader deterioration of ground support and accessibility.

Electrical, equipment, visibility, and flooding hazards

Electrical hazards provide another mechanism through which rainfall may amplify existing construction risk. Chi et al., (2009) analysed 255 fatal electrocution cases in the construction industry and included wet working areas among the environmental factors considered in identifying accident patterns. Their analysis demonstrated that electrical fatalities result from combinations of worker, task, equipment, management, and environmental conditions rather than from electricity exposure alone. Research on construction electrical-hazard controls has similarly shown that electrocution remains a persistent concern despite the long-standing availability of control measures. The implication is not that rainfall inevitably produces electrical accidents, but that water exposure may reduce the tolerance for deficiencies in temporary wiring, damaged equipment, electrical isolation, connections, and work practices. Thus, a rainfall-specific electrical-hazard assessment complements rather than replaces conventional electrical safety assessment. This distinction is important because attributing an electrical incident solely to “rain” could obscure underlying failures in equipment condition, design, supervision, or control procedures. Machinery and vehicle operations represent another potentially interacting hazard. Construction equipment frequently operates in dynamic environments where workers, vehicles, plant, and temporary routes overlap. Mohammadi et al., (2018) identified work visibility and heavy equipment among project-level influences considered in construction safety research. Rainfall may therefore affect safety indirectly if visibility is reduced or if ground and access conditions alter vehicle movement. However, compared with slips, falls, and electrical hazards, direct empirical evidence quantifying the effect of rainfall specifically on construction-equipment accidents remains limited. This limitation supports treating machinery-related rainfall risk as an empirical question rather than assuming its importance from general safety theory. Flooding represents a more severe environmental manifestation. Malaysia's rainfall regime makes this particularly relevant. METMalaysia describes the country as having an equatorial climate characterised by high humidity and copious rainfall, with exposed areas experiencing heavy rain spells during the Northeast Monsoon. The agency also notes that heavy monsoon rainfall frequently contributes to major flooding in parts of Peninsular Malaysia, Sarawak, and Sabah. Construction sites may be especially sensitive because permanent drainage, ground surfaces, access systems, and protective works can remain incomplete during project execution. Nevertheless, site flooding should not automatically be interpreted as an inevitable consequence of heavy rainfall; drainage capacity, topography, temporary works, maintenance, and project stage are also likely to determine whether rainfall develops into a hazardous site condition (METMalaysia, 2026).

Human and organisational mechanisms under rainy conditions

Not all perceived rainfall-related safety hazards are purely physical. Construction accidents emerge from interactions between environmental conditions and human or organisational performance. Safety-performance reviews show that management, communication, training, supervision, worker behaviour, and physical working conditions operate jointly rather than independently. Accordingly, rainfall-related safety assessment should include the possibility that adverse weather affects concentration, communication, coordination, compliance with protective equipment requirements, or decisions about whether an activity should continue. For instance, deteriorating visibility may influence both hazard detection and communication between workers, equipment operators, banksmen, and supervisors. Rain may also create competing task demands: workers may attempt to protect materials, complete activities before conditions worsen, relocate equipment, or respond to water accumulation while continuing normal construction operations. These pathways are plausible within established

construction-safety frameworks, but direct rainfall-specific evidence remains comparatively limited. They should therefore be treated as hypotheses requiring empirical evaluation rather than established causal effects. The role of personal protective equipment (PPE) should also be considered critically. Wet-weather clothing, appropriate footwear, electrical protection, and fall-protection systems may reduce specific exposures, but PPE occupies only one layer of risk control. Construction-safety research repeatedly shows that safety performance depends on organisational systems as well as individual protection. Similarly, Baek & Choi, (2026) argue that climate-related worker protection requires organisational investment, weather-contingent scheduling, education, policy integration, and management capacity rather than fragmented protective measures alone. The implication for rainy-weather safety is that PPE should complement decisions about work suspension, drainage, access control, electrical isolation, communication, and activity sequencing rather than substitute for them. This broader approach is consistent with the concept of safety climate. Schwatka et al., (2016), reviewing 56 construction safety-climate studies, found that safety policies, procedures, management commitment, and worker-level actions are repeatedly reflected in construction safety perceptions. They also observed that many safety-climate studies rely on subjective behavioural indicators rather than objective injury outcomes. This methodological limitation is also relevant to rainfall-hazard surveys. Practitioner perceptions are valuable for identifying hazards, but high perceived risk should not be interpreted automatically as evidence of higher actual accident frequency.

Malaysian construction safety and the need for rainfall-responsive risk management

The Malaysian context provides a strong justification for examining rainfall-related construction hazards. Malaysia experiences abundant rainfall and marked monsoon influences, making wet conditions a recurrent feature of the construction environment. At the same time, construction remains an important occupational-safety concern. DOSH reported that the Malaysian construction sector recorded 194 occupational injuries and 67 fatal injuries in 2023, with construction contributing the highest number of fatal occupational injuries among sectors reported for that year. Malaysia's regulatory framework has also moved toward more proactive construction-risk management. The Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 were introduced under the Occupational Safety and Health Act framework, with duties allocated across construction stakeholders. DOSH states that the regulations came into effect on 1 June 2024 and are intended to promote safer management across construction project stages. This regulatory shift strengthens the argument that environmental hazards such as rainfall should be incorporated into systematic risk assessment rather than addressed only after unsafe conditions occur. However, Malaysian construction-safety studies have primarily examined broad sets of accident factors. Manzoor et al., (2021) investigated 62 safety factors associated with high-rise construction, while Waqar et al., (2024) examined accident-related safety factors in downstream oil and gas construction and identified training, procedures, and supervision as important concerns. These studies are valuable for establishing the broader Malaysian safety context, but neither provides a detailed multidimensional analysis specifically of rainfall-related hazards. Therefore, there remains scope for research asking not merely whether adverse weather matters, but which types of construction hazard practitioners associate most strongly with rainy conditions.

Limitations of conventional hazard ranking

Questionnaire-based construction research frequently uses means, percentages, or importance indices to rank safety factors. Ranking is useful because it can identify practitioner priorities, but it has an important limitation: it treats each item as though it represents an independent problem. In reality, hazards such as slippery surfaces, unstable ground, flooding, electrical exposure, machinery operation, working at height, reduced concentration, PPE, and communication may cluster into broader underlying dimensions. This matters analytically. If several observed hazards are manifestations of a common underlying domain, a simple rank order may overstate the independence of those hazards. Conversely, forcing all hazards into a single overall safety-risk score may conceal meaningful distinctions. Construction safety literature already suggests that risk is multidimensional and arises through interactions among physical, human, organisational, and environmental factors. Consequently, an exploratory factor approach is appropriate when the objective is not only to rank rainfall-related hazards but also to determine whether practitioners perceive them as belonging to broader safety-risk dimensions. Previous Malaysian research demonstrates that factor-analytical methods can be useful for structuring complex safety-factor data. Waqar et al., (2024), for example, applied exploratory factor analysis before structural modelling in their study of safety factors in Malaysian downstream oil and gas construction. However, the conceptual

contribution of the present study differs because the proposed factors are restricted specifically to rainfall-related safety conditions, rather than general causes of construction accidents.

Research gap and conceptual direction

The reviewed literature supports several conclusions. First, construction safety is generated by interactions among physical, human, organisational, equipment, and environmental factors rather than by isolated hazards. Second, empirical accident evidence demonstrates that weather—and rainfall specifically—can be associated with construction injuries and fatalities. Third, established evidence links environmental conditions to hazards such as slips and falls and identifies wet environments as relevant in electrical-fatality analysis. Fourth, climate-related construction research is expanding, but much of the evidence remains concentrated on heat and health rather than rainfall-specific accident mechanisms. The resulting gap is therefore more specific than a general absence of construction-safety research. What remains comparatively underdeveloped is an integrated assessment of how construction practitioners in a tropical environment perceive and structure multiple safety hazards associated specifically with rainfall. Existing accident-record studies provide evidence after harmful events, while general construction-safety surveys typically combine weather with many unrelated factors. Neither approach fully establishes whether rainfall-related hazards such as slips, ground instability, equipment and electrical risks, work-at-height exposure, flooding, reduced alertness, PPE, and communication difficulties constitute one general risk domain or several distinguishable dimensions. Accordingly, the present study adopts a practitioner-based exploratory approach to rainfall-related construction safety in Malaysia. It seeks to (1) identify and prioritise rainfall-related safety hazards, (2) determine the underlying dimensions represented by these hazards using exploratory factor analysis, and (3) examine whether hazard perceptions differ across selected practitioner characteristics. Rather than assuming in advance that all rainfall-related hazards belong to a single construct, the study allows the empirical factor structure to determine whether physical/environmental, equipment-related, and human/organisational dimensions can be distinguished. This approach is expected to provide a more structured basis for rainy-weather risk assessment and targeted construction-safety management in tropical environments.

METHODOLOGY

Research Design

This study adopted a quantitative cross-sectional survey design to investigate practitioners' perceptions of rainfall-related safety hazards on construction sites in Malaysia. A structured questionnaire was used to obtain information from construction personnel representing technical, managerial, supervisory, safety, and operational roles. The survey approach was considered appropriate because it enabled the systematic assessment and comparison of multiple rainfall-related hazards based on practitioners' site experience.

Questionnaire Development and Measurement

For this paper, the analysis focused on Section A and Section C of the questionnaire. Section A collected respondents' demographic and professional characteristics, including gender, age, construction-site role, work experience, and education level. Section C comprised 10 items (C1–C10) assessing safety hazards associated with rainy conditions, including slippery surfaces, unstable ground, machinery and vehicle operations, electrical hazards, working at height, flooding, equipment performance, worker concentration, personal protective equipment, and communication or coordination difficulties. All hazard items were measured using a five-point Likert scale, with higher scores representing stronger agreement that the stated condition constituted a rainfall-related safety concern. A total of 128 valid responses were included in the analysis. Participation was voluntary, and responses were analysed in aggregate form to maintain respondent confidentiality.

Data Analysis

Data were analysed using IBM SPSS Statistics. The analysis was conducted in several stages. First, the dataset was screened for missing data, coding errors, and response distributions. Descriptive statistics, including frequencies, percentages, means, standard deviations, and agreement percentages, were used to identify and rank

the rainfall-related safety hazards. Because the same respondents evaluated all 10 hazards, the Friedman test was used to determine whether the perceived importance of the hazards differed significantly across items. Where a significant overall difference was identified, appropriate pairwise comparisons were considered to identify the hazards contributing to the difference. Exploratory Factor Analysis (EFA) was then performed to examine whether the 10 hazard items formed broader underlying safety-risk dimensions. The suitability of the data for factor analysis was assessed using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett’s Test of Sphericity. Principal Axis Factoring was employed as the extraction method, together with an oblique rotation where more than one factor was retained, as the underlying safety dimensions were expected to be conceptually related. Factor retention was evaluated using eigenvalues, the scree plot, factor loadings, communalities, and interpretability of the resulting solution. Internal consistency of the retained factor or factors was assessed using Cronbach’s alpha and corrected item–total correlations. Composite mean scores were subsequently calculated for statistically and conceptually supported dimensions. Differences in rainfall-related hazard perceptions according to selected practitioner characteristics were examined using independent-samples *t*-tests, one-way ANOVA, or appropriate non-parametric alternatives. Where the homogeneity-of-variance assumption was violated, Welch’s ANOVA and Games–Howell post-hoc comparisons were used. The Kruskal–Wallis test was applied where group sizes were highly unequal and the assumptions for parametric analysis were considered inappropriate. Statistical significance was evaluated at $p < .05$.

Ethical Considerations

Participation in the survey was voluntary, and respondents were informed of the purpose of the research prior to completing the questionnaire. No personally identifying information was required, and all responses were treated confidentially and used solely for academic research. Results were reported only in aggregated form to protect the anonymity of individual participants.

RESULTS AND ANALYSIS

Respondent profile

Table 1. Profile of respondents

		N	%
A1. Gender	Male	50	39%
	Female	78	61%
A2. Age	Below 25 years	9	7%
	25 - 34 years	64	50%
	35 - 44 years	30	23%
	45 - 54 years	21	16%
	55 years and above	4	3%
A3. Role at the construction site	Architect	14	11%
	Consultant	17	13%
	Project Manager	13	10%
	Site Engineer	16	13%

	Site Supervisor	13	10%
	DOSH Officer	15	12%
	Safety Officer (SHO)	16	13%
	Site Safety Supervisor	12	9%
	Construction Worker / Labourer	12	9%
A4. Work experience	Less than 1 year	9	7%
	1 - 5 years	40	31%
	6 - 10 years	53	41%
	11 - 20 years	23	18%
	More than 20 years	3	2%
A5. Education level	No formal qualification	5	4%
	SPM / STPM or equivalent	25	20%
	Diploma	26	20%
	Bachelor's Degree	54	42%
	Master's Degree or above	18	14%

Table 1 shows that the 128 respondents were predominantly female (61%) and aged 25–34 years (50%). Respondents represented various construction-related roles, with consultants, site engineers, and Safety and Health Officers among the largest groups. Most had 6–10 years of work experience (41%), while 42% held a bachelor’s degree. Overall, the sample reflects a reasonably diverse group of construction practitioners in terms of role, experience, and education.

Perceived Rainfall-Related Safety Hazards

Table 2. Descriptive Statistics and Ranking of Perceived Rainfall-Related Safety Hazards

	Percentage (%)					Mean	Std. Deviation	Rank
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree			
C1. Slippery surfaces (walkways, scaffolds, floors) increase the risk of falls during rainfall.	4	6	13	37	41	4.04	1.068	7
C2. Reduced visibility during rainfall increases the risk of accidents involving moving equipment or vehicles.	7	8	12	30	44	3.95	1.229	10

C3. Ground instability (soil erosion, slope failure) poses a risk during heavy rainfall.	2	7	13	35	42	4.08	1.024	5
C4. Electrical hazards (exposed wiring, faulty equipment) become more dangerous during wet conditions.	3	7	14	30	46	4.09	1.080	4
C5. Working at height during rainfall significantly increases the risk of falls and injuries.	2	7	18	32	41	4.02	1.042	8
C6. Equipment and machinery performance is compromised during rainy conditions, increasing accident risks.	5	6	10	33	46	4.09	1.111	3
C7. Flooding of work areas during heavy rainfall creates hazardous conditions for workers.	7	5	13	31	44	4.00	1.184	9
C8. Workers' concentration and alertness are reduced during prolonged rainfall, increasing accident risks.	5	5	12	33	45	4.08	1.120	6
C9. Inadequate PPE for rainy conditions increases safety risks on site.	3	5	13	34	45	4.11	1.037	2
C10. Poor communication and reduced coordination among workers during rainfall increase accident risks.	2	5	13	35	45	4.16	0.959	1

Table 2 presents the respondents' perceptions of ten rainfall-related safety hazards on construction sites. Overall, all items recorded relatively high mean scores, ranging from 3.95 to 4.16, indicating that respondents generally agreed that the listed conditions represent important safety concerns during rainfall. Poor communication and reduced coordination among workers during rainfall (C10) recorded the highest mean score ($M = 4.16$, $SD = 0.959$), followed by inadequate PPE for rainy conditions (C9) ($M = 4.11$, $SD = 1.037$). Equipment and machinery performance (C6) and electrical hazards (C4) also received relatively high ratings, with mean scores of 4.09. In contrast, reduced visibility during rainfall (C2) recorded the lowest mean score ($M = 3.95$, $SD = 1.229$), followed by flooding of work areas (C7) ($M = 4.00$, $SD = 1.184$). Despite these differences in descriptive ranking, all ten items recorded mean scores close to or above 4.00, suggesting that practitioners generally perceived rainfall-related hazards as important safety concerns across physical, operational, and human-related aspects of construction work. However, the descriptive ranking alone does not establish whether the differences among the ten hazard ratings are statistically significant; this was subsequently examined using the Friedman test. A Friedman test was conducted to determine whether practitioners differed in their ratings of the ten rainfall-related safety hazards. The results showed no statistically significant difference among the ten hazard ratings, $\chi^2(9, N = 128) = 4.961$, $p = .838$, Kendall's $W = .004$. Although C10, concerning poor communication and reduced coordination during rainfall, recorded the highest mean rank (5.74), while C7, concerning flooding of work areas, recorded the lowest mean rank (5.25), these differences were not statistically significant. The findings therefore indicate that respondents generally perceived the ten rainfall-related hazards as similarly important safety concerns.

Reliability of the Rainfall-Related Safety Hazard Items

Table 3. Reliability Analysis

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardised Items	N of Items
0.920	0.920	10

Table 3 shows that the ten rainfall-related safety-hazard items demonstrated excellent internal consistency, with Cronbach's alpha of $\alpha = .920$. The standardized alpha was also .920, indicating that the reliability estimate was unaffected by differences in item variances. Overall, the result indicates a high degree of internal consistency among the ten rainfall-related safety-hazard items. The dimensional structure of the items was subsequently examined using exploratory factor analysis.

Underlying Dimensions of Rainfall-Related Safety Hazards

Exploratory Factor Analysis (EFA) was conducted on the ten rainfall-related safety hazard items (C1–C10) to identify their underlying dimensional structure. Principal Axis Factoring (PAF) was used as the extraction method, while Direct Oblimin rotation with Kaiser normalisation was applied because the underlying safety dimensions were expected to be correlated.

Table 4. KMO and Bartlett's Test for Rainfall-Related Safety Hazard Items

Test	Statistic
Kaiser–Meyer–Olkin Measure of Sampling Adequacy	0.821
Bartlett's Test of Sphericity: Approx. χ^2	893.699
df	45
Sig.	< .001

The suitability of the ten rainfall-related safety hazard items for factor analysis was first examined using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity. As shown in Table 4, the KMO value was 0.821, indicating good sampling adequacy. Bartlett's Test of Sphericity was also statistically significant, $\chi^2(45) = 893.699$, $p < .001$, demonstrating that the correlations among the ten items were sufficiently strong to support factor analysis. Therefore, the C1–C10 data were considered appropriate for EFA.

Table 5. Total Variance Explained for Rainfall-Related Safety Hazard Factors

Factor	Initial Eigenvalue	% of Variance	Cumulative %
1	5.831	58.315	58.315
2	1.224	12.242	70.556
3	0.743	7.429	77.985

Extraction method: Principal Axis Factoring.

Principal Axis Factoring initially produced two factors with eigenvalues greater than 1.00 (5.831 and 1.224). Inspection of the scree plot also indicated a clear break following the second factor, while subsequent

eigenvalues declined substantially. The two-factor solution was further supported by its interpretability, satisfactory communalities, and relatively clear pattern of primary loadings. Accordingly, two factors were retained. Together, they accounted for 70.556% of the total variance before rotation.

Table 6. Communalities and Rotated Factor Loadings for Rainfall-Related Safety Hazards

Code	Rainfall-related safety hazard	Extraction Communality	Factor 1	Factor 2
C1	Slippery surfaces	0.593	0.708	—
C3	Ground instability	0.780	0.944	—
C5	Working at height during rainfall	0.626	0.633	—
C7	Flooding of work areas	0.633	0.754	—
C9	Inadequate PPE for rainy conditions	0.711	0.875	—
C2	Reduced visibility	0.745	—	0.808
C4	Electrical hazards	0.659	—	0.711
C6	Compromised equipment and machinery performance	0.526	—	0.717
C8	Reduced worker concentration and alertness	0.517	—	0.493
C10	Poor communication and reduced coordination	0.554	—	0.817

Note: Extraction method = Principal Axis Factoring. Rotation method = Direct Oblimin with Kaiser normalisation. Loadings below 0.30 are suppressed.

As presented in Table 6, extraction communalities ranged from 0.517 to 0.780, indicating that all ten items were adequately represented by the retained factor solution. The highest communality was recorded for C3, concerning ground instability (0.780), followed by C2, concerning reduced visibility (0.745), and C9, concerning inadequate rainy-condition PPE (0.711). The lowest communalities were recorded for C8 (0.517) and C6 (0.526); however, both remained satisfactory. Consequently, no item was removed on the basis of low communality. The rotated pattern matrix revealed a relatively clear two-factor structure. Factor 1 consisted of C1, C3, C5, C7 and C9, with primary factor loadings ranging from 0.633 to 0.944. These items primarily represent workers' direct exposure to hazardous physical site conditions associated with rainfall, including slippery surfaces, unstable ground, working at height, flooding and insufficient personal protective equipment. Based on the conceptual content of these items, Factor 1 was labelled Site Exposure and Physical Hazards (SEPH). Factor 2 comprised C2, C4, C6, C8 and C10, with primary loadings ranging from 0.493 to 0.817. These items represent rainfall-related conditions that may affect the safe operation, control and coordination of construction activities, including reduced visibility, electrical hazards, machinery performance, worker concentration and communication. Factor 2 was therefore labelled Operational and Human-Factor Hazards (OHFH). The loading pattern showed limited evidence of problematic cross-loading. In particular, C3 (0.944), C9 (0.875), C2 (0.808) and C10 (0.817) demonstrated strong and clearly differentiated primary loadings. C8 recorded the lowest primary loading at 0.493 on Factor 2 and a secondary loading of 0.290 on Factor 1. However, its extraction communality remained satisfactory at 0.517, and the item was theoretically relevant to human-factor safety under prolonged rainfall. C8 was therefore retained in the factor structure. Overall, the results indicate that rainfall-related construction-site safety hazards are not perceived as a single homogeneous category. Instead, practitioners distinguish between hazards associated with direct physical and site exposure and hazards associated with the safe operation, human performance and coordination of construction activities.

Table 7. Factor Correlation Matrix for Rainfall-Related Safety Hazard Dimensions

Factor	1	2
1. Site Exposure and Physical Hazards (SEPH)	1.000	0.664
2. Operational and Human-Factor Hazards (OHFH)	0.664	1.000

Extraction method: Principal Axis Factoring. Rotation method: Direct Oblimin with Kaiser normalisation.

The factor correlation matrix in Table 7 shows a positive correlation of 0.664 between Site Exposure and Physical Hazards and Operational and Human-Factor Hazards. This moderately strong relationship indicates that respondents who perceived greater physical rainfall-related hazards also tended to perceive greater operational and human-factor hazards. The correlation further supports the use of Direct Oblimin rotation, as the two dimensions are clearly related rather than statistically independent. At the same time, the correlation does not indicate complete overlap between the two factors. Combined with the distinct pattern of item loadings, the result supports treating SEPH and OHFH as related but distinguishable dimensions of rainfall-related construction safety hazards.

Reliability Analysis of the Extracted Safety-Hazard Dimensions

Table 8. Reliability and Item-Total Statistics for Rainfall-Related Safety Hazard Dimensions

Construct	Item	Corrected Item–Total Correlation	Cronbach’s α if Item Deleted
Site Exposure and Physical Hazards (SEPH)	C1	0.746	0.888
	C3	0.807	0.876
	C5	0.750	0.887
	C7	0.736	0.892
	C9	0.785	0.880
Overall SEPH reliability	5 items		$\alpha = 0.905$
Operational and Human-Factor Hazards (OHFH)	C2	0.782	0.829
	C4	0.769	0.833
	C6	0.664	0.858
	C8	0.654	0.861
	C10	0.663	0.859
Overall OHFH reliability	5 items		$\alpha = 0.875$

Note: Corrected item–total correlations above .30 indicate satisfactory item consistency. Cronbach’s alpha values above .70 indicate acceptable internal consistency.

The internal consistency of the two dimensions identified through exploratory factor analysis was assessed separately using Cronbach’s alpha. As shown in Table 8, the five-item Site Exposure and Physical Hazards

(SEPH) scale demonstrated excellent internal consistency, with a Cronbach's alpha of .905. Corrected item-total correlations ranged from .736 to .807, indicating that all five items were strongly associated with the overall SEPH scale. Among the SEPH items, C3, concerning ground instability during heavy rainfall, recorded the strongest corrected item-total correlation ($r = .807$), followed by C9, concerning inadequate PPE for rainy conditions ($r = .785$). The remaining items also demonstrated strong corrected item-total correlations, ranging from .736 to .750. Moreover, Cronbach's alpha if an item was deleted ranged from .876 to .892, all lower than the overall alpha of .905. Therefore, removal of any SEPH item would reduce rather than improve the reliability of the scale. Consequently, C1, C3, C5, C7 and C9 were retained. The five-item Operational and Human-Factor Hazards (OHFH) scale also demonstrated good internal consistency, with a Cronbach's alpha of .875. Corrected item-total correlations ranged from .654 to .782, substantially exceeding the minimum acceptable criterion. C2, concerning reduced visibility during rainfall, recorded the highest corrected item-total correlation ($r = .782$), followed by C4, concerning electrical hazards ($r = .769$). C6, C8 and C10 also showed satisfactory relationships with the total OHFH score, with correlations between .654 and .664. Cronbach's alpha if an OHFH item was deleted ranged from .829 to .861, which was lower than the overall reliability coefficient of .875 in every case. This indicates that none of the items weakened the internal consistency of the scale. Therefore, C2, C4, C6, C8 and C10 were retained. Overall, the reliability analysis provides further support for the two-factor structure identified in the EFA. SEPH demonstrated high internal consistency ($\alpha = .905$), while OHFH demonstrated good internal consistency ($\alpha = .875$). The consistently high corrected item-total correlations and lower alpha-if-item-deleted values indicate that all ten items contribute meaningfully to their respective dimensions.

Table 9. Descriptive Statistics of Rainfall-Related Safety Hazard Dimensions

Dimension	N	Minimum	Maximum	Mean	Std. Deviation
SEPH	128	1.20	5.00	4.0484	0.91350
OHFH	128	1.80	5.00	4.0734	0.90070

As shown in Table 9, both rainfall-related safety-hazard dimensions recorded high mean scores, indicating that respondents generally perceived both dimensions as important safety concerns under rainy conditions. OHFH recorded a slightly higher descriptive mean ($M = 4.073$, $SD = 0.901$) than SEPH ($M = 4.048$, $SD = 0.914$). However, the difference was very small and should be interpreted descriptively rather than as evidence that one dimension was perceived as significantly more important than the other.

Differences in Rainfall-Related Safety-Hazard Dimensions According to Practitioner Characteristics

Table 10. Independent-samples t-tests

Dimension	Male (SD)	Female (SD)	t	df	p	95% CI	Cohen's d
SEPH	3.964 (0.888)	4.103 (0.931)	-0.836	126	.405	[-0.466, 0.189]	-0.15
OHFH	4.000 (0.879)	4.121 (0.917)	-0.737	126	.462	[-0.444, 0.203]	-0.13

Independent-samples t-tests as in Table 10 were conducted to examine whether perceptions of rainfall-related safety hazards differed according to gender. For Site Exposure and Physical Hazards (SEPH), female respondents reported a slightly higher mean score ($M = 4.103$, $SD = 0.931$) than male respondents ($M = 3.964$, $SD = 0.888$); however, the difference was not statistically significant, $t(126) = -0.836$, $p = .405$, 95% CI [-0.466, 0.189], Cohen's $d = -0.15$. Similarly, female respondents recorded a slightly higher mean score for Operational and Human-Factor Hazards (OHFH) ($M = 4.121$, $SD = 0.917$) than male respondents ($M = 4.000$, $SD = 0.879$), but the difference was also not statistically significant, $t(126) = -0.737$, $p = .462$, 95% CI [-0.444, 0.203], Cohen's $d = -0.13$. These results indicate that perceptions of both rainfall-related safety-hazard dimensions were broadly similar across male and female practitioners.

Table 11. Differences in Rainfall-Related Safety-Hazard Dimensions Across Age Groups

Dimension	Age group	N	Mean	SD	ANOVA F	p	Welch F	p	η^2
SEPH	Below 25 years	9	3.533	0.812	1.741	.145	1.933	.149	0.054
	25–34 years	64	4.222	0.931					
	35–44 years	30	4.013	0.938					
	45–54 years	21	3.867	0.833					
	55 years and above	4	3.650	0.574					
OHFH	Below 25 years	9	3.467	0.831	2.616	.038	3.783	.022	0.078
	25–34 years	64	4.219	0.836					
	35–44 years	30	4.067	0.884					
	45–54 years	21	4.076	1.044					
	55 years and above	4	3.150	0.574					

Table 11 presents differences in the two rainfall-related safety-hazard dimensions across respondents' age groups. For Site Exposure and Physical Hazards (SEPH), the highest mean score was recorded among respondents aged 25–34 years ($M = 4.222$, $SD = 0.931$), while respondents below 25 years recorded the lowest mean ($M = 3.533$, $SD = 0.812$). However, the one-way ANOVA showed that the differences across age groups were not statistically significant, $F(4, 123) = 1.741$, $p = .145$, $\eta^2 = .054$. Welch's robust test produced a similar result, $F(4, 17.755) = 1.933$, $p = .149$. Thus, perceptions of site exposure and physical hazards were generally comparable across age groups. For Operational and Human-Factor Hazards (OHFH), respondents aged 25–34 years recorded the highest mean score ($M = 4.219$, $SD = 0.836$), whereas respondents aged 55 years and above recorded the lowest mean ($M = 3.150$, $SD = 0.574$). The overall difference across age groups was statistically significant, $F(4, 123) = 2.616$, $p = .038$, $\eta^2 = .078$. Welch's robust test also indicated a significant overall difference, $F(4, 17.400) = 3.783$, $p = .022$. However, subsequent Tukey HSD and Games–Howell comparisons did not identify statistically significant differences between any specific pairs of age groups (all $p > .05$). Therefore, although the omnibus analyses indicated overall variation in OHFH scores across age groups, the post-hoc analyses did not establish which specific age groups differed.

Table 12. Differences in Rainfall-Related Safety-Hazard Dimensions According to Work Experience

Dimension	Work experience	N	Mean rank	Kruskal–Wallis H	df	p
SEPH	<1 year	9	48.00	11.985	4	.017
	1–5 years	40	67.85			
	6–10 years	53	72.02			
	11–20 years	23	54.09			
	>20 years	3	16.33			
OHFH	<1 year	9	44.06	10.978	4	.027

	1–5 years	40	68.85			
	6–10 years	53	68.66			
	11–20 years	23	62.26			
	>20 years	3	11.50			

A Kruskal–Wallis test was conducted to examine whether perceptions of rainfall-related safety hazards differed according to respondents’ work experience. A statistically significant overall difference was found for Site Exposure and Physical Hazards (SEPH), $H(4) = 11.985$, $p = .017$, $\varepsilon^2 = .065$. Respondents with 6–10 years of experience recorded the highest mean rank (72.02), while those with more than 20 years of experience recorded the lowest mean rank (16.33). However, Bonferroni-adjusted pairwise comparisons did not identify any statistically significant differences between specific work-experience groups (all adjusted $p > .05$). A statistically significant overall difference was also observed for Operational and Human-Factor Hazards (OHFH), $H(4) = 10.978$, $p = .027$, $\varepsilon^2 = .057$. Respondents with 1–5 years of experience recorded the highest mean rank (68.85), closely followed by those with 6–10 years of experience (68.66), whereas respondents with more than 20 years of experience recorded the lowest mean rank (11.50). Nevertheless, none of the Bonferroni-adjusted pairwise comparisons was statistically significant (all adjusted $p > .05$). Therefore, although the omnibus tests indicate that perceptions of both safety-hazard dimensions vary overall according to work experience, the analysis does not provide sufficient evidence to identify a specific pair of experience groups as significantly different. The findings should also be interpreted cautiously because only three respondents had more than 20 years of experience.

DISCUSSION

This study examined rainfall-related safety hazards on Malaysian construction sites from three complementary perspectives: the perceived importance of individual hazards, the underlying dimensional structure of those hazards, and differences in perceptions according to selected practitioner characteristics. Rather than treating rainfall as a single stand-alone hazard, the study considered how rainy conditions may intensify physical, equipment-related, operational and human aspects of construction safety. This approach is consistent with the broader view that construction safety results from interactions among workers, tasks, equipment, site conditions and organisational systems.

Perceived importance of rainfall-related safety hazards

The first objective was to identify and prioritise rainfall-related safety hazards affecting construction sites. All ten assessed hazards obtained relatively high mean scores, ranging from 3.95 to 4.16. Poor communication and reduced coordination during rainfall (C10) recorded the highest descriptive mean, followed by inadequate PPE for rainy conditions (C9). Electrical hazards, compromised equipment and machinery performance, ground instability and reduced worker concentration also received relatively high ratings. At the other end of the descriptive ranking, reduced visibility involving moving equipment or vehicles recorded the lowest mean, although its mean remained close to 4.00. The overall pattern therefore indicates that practitioners regarded the entire set of rainfall-related conditions as relevant safety concerns rather than identifying only one or two dominant problems. The Friedman test provides an important qualification to the descriptive ranking. Although C10 obtained the highest mean rank and C7 the lowest, the overall difference among the ten hazards was not statistically significant, $\chi^2(9, N = 128) = 4.961$, $p = .838$, Kendall's $W = .004$. Thus, the ranking should not be interpreted as evidence that poor communication is statistically more important than flooding, visibility, working at height or the other assessed hazards. Instead, the extremely small Kendall's W suggests that respondents evaluated the ten hazards at broadly comparable levels. This finding is practically meaningful because rainfall can influence construction safety through several concurrent mechanisms. Wet surfaces can reduce traction, unstable ground can affect workers and plant, rainfall can increase concerns surrounding temporary electrical installations, and deteriorating visibility can interfere with equipment movement and hazard detection. At the same time, rain can influence communication, concentration, coordination and decisions about whether work

should continue. The literature therefore supports viewing rainfall as a condition capable of amplifying existing construction hazards, rather than as one isolated hazard with a single control measure. The relatively high rating given to communication and coordination is also notable. During rainfall, workers may need to respond simultaneously to changing access conditions, water accumulation, material protection, machinery movements and decisions to interrupt or resequence activities. Such circumstances can increase the importance of clear communication between workers, equipment operators, supervisors and other personnel. Previous literature similarly recognises that environmental conditions interact with communication, supervision, worker behaviour and organisational practices rather than operating independently.

The high descriptive rating for inadequate rainy-condition PPE should likewise not be interpreted to mean that PPE alone represents the primary solution to rainy-weather risks. PPE constitutes only one layer of control. Rain-responsive safety management also requires attention to drainage, access control, electrical isolation, work suspension criteria, communication and activity sequencing. This interpretation is consistent with the argument that climate-related worker protection should combine individual protective measures with organisational planning and management controls. Overall, the finding addressing RO1 suggests that rainy-weather construction safety should be approached comprehensively. The absence of statistically significant differences among the ten hazard ratings indicates that it would be inappropriate to focus preventive resources exclusively on the top-ranked items while disregarding lower-ranked hazards. The findings instead support a broad rainfall-responsive risk assessment that considers physical site conditions, equipment, electrical systems, human performance and coordination simultaneously.

Underlying dimensions of rainfall-related safety hazards

The second objective was to determine the underlying dimensions of rainfall-related construction safety risk. The EFA demonstrated that the data were suitable for factor analysis, with a KMO value of 0.821 and a significant Bartlett's Test of Sphericity, $\chi^2(45) = 893.699$, $p < .001$. The ten items formed two interpretable dimensions: Site Exposure and Physical Hazards (SEPH) and Operational and Human-Factor Hazards (OHFH). SEPH comprised slippery surfaces, ground instability, working at height during rainfall, flooding and inadequate rainy-condition PPE. These items primarily reflect workers' direct exposure to adverse site conditions and the protective measures required when working in wet environments. OHFH comprised reduced visibility, electrical hazards, compromised equipment and machinery performance, reduced worker concentration and alertness, and poor communication and coordination. These items represent how rainfall can affect the safe operation, control and coordination of construction activities. The emergence of two dimensions provides empirical support for the multidimensional conceptualisation proposed in the literature review. Construction safety research has long suggested that accident risk involves interactions among physical, human, organisational, equipment and environmental influences. The present study extends this reasoning specifically to rainfall-related conditions by showing that practitioners do not appear to perceive all rainy-weather hazards as one undifferentiated construct. Instead, direct site exposure can be distinguished from operational and human-factor concerns. At the same time, the two dimensions were positively related, with a factor correlation of 0.664. This relationship indicates that practitioners who reported stronger concerns regarding physical site exposure also tended to report stronger concerns regarding operational and human-factor hazards. The dimensions should therefore be viewed as distinct but interconnected, rather than independent categories. This interconnectedness is plausible within actual construction operations. For example, flooding or unstable ground is primarily a physical condition, but it can also affect vehicle movement, equipment operation, communication and worker concentration. Likewise, reduced visibility is classified within the operational dimension but may intensify the physical consequences associated with work at height or moving equipment. The two-factor structure therefore offers a practical way to organise rainfall-related hazards without implying that the dimensions operate separately on site. The reliability analysis further supports the usefulness of the two dimensions. SEPH demonstrated excellent internal consistency ($\alpha = .905$), while OHFH demonstrated good internal consistency ($\alpha = .875$). Corrected item-total correlations were satisfactory for all items, and deletion of individual items did not improve the reliability coefficients. These results suggest that the two scales provide internally consistent measures of rainfall-related safety perceptions within the present sample. The two-dimensional structure also contributes beyond conventional hazard ranking. Simple rankings identify which individual hazards receive higher mean ratings, but they may obscure common mechanisms connecting apparently different hazards. The present findings show that rainfall-related risks can instead be organised into broader domains that may be more useful for planning

inspections, toolbox briefings and rainy-weather risk assessments. This directly addresses the research gap identified in the literature, where rainfall-specific hazards have often been incorporated into broader accident-factor studies rather than analysed as a structured safety domain in their own right.

Differences according to practitioner characteristics

The third objective was to examine whether perceptions of the two rainfall-related safety-hazard dimensions varied according to selected practitioner characteristics. For gender, no statistically significant differences were found. Male and female practitioners reported broadly similar perceptions of both SEPH and OHFH. For SEPH, the difference was not significant, $t(126) = -0.836, p = .405$, and the effect size was very small. Similarly, OHFH did not differ significantly by gender, $t(126) = -0.737, p = .462$. These findings indicate that awareness of rainfall-related physical, operational and human-factor hazards was broadly shared across male and female respondents rather than being strongly differentiated by gender. Age produced a more nuanced pattern. SEPH did not differ significantly across age groups, $F(4, 123) = 1.741, p = .145$. In contrast, the overall ANOVA for OHFH was significant, $F(4, 123) = 2.616, p = .038, \eta^2 = .078$, and this finding was supported by Welch's robust test, $p = .022$. However, neither Tukey HSD nor Games-Howell comparisons identified a statistically significant difference between any specific pair of age groups after adjustment for multiple comparisons. The result therefore suggests some overall age-related variation in operational and human-factor perceptions, but the available evidence does not establish which particular age groups differ from one another. The age result should also be interpreted cautiously because group sizes were uneven. Half of the sample was aged 25–34 years, whereas only four respondents were aged 55 years and above. The respondent profile therefore provides considerably more information about the perceptions of younger and middle-career practitioners than about the oldest age category. This uneven representation may partly explain why an omnibus difference was detected for OHFH while individual post-hoc comparisons did not remain significant. Work experience also showed significant overall variation. Because the experience groups were highly unequal and the more-than-20-years category contained only three respondents, the Kruskal-Wallis test was used as the more cautious inferential approach. Significant overall differences were found for both SEPH, $H(4) = 11.985, p = .017$, and OHFH, $H(4) = 10.978, p = .027$. For SEPH, the highest mean rank occurred among respondents with 6–10 years of experience, whereas those with more than 20 years had the lowest mean rank. For OHFH, respondents with 1–5 years and 6–10 years recorded the highest mean ranks, while the more-than-20-years group recorded the lowest. Nevertheless, the Bonferroni-adjusted pairwise comparisons did not identify statistically significant differences between any specific work-experience groups. Consequently, it would be inappropriate to conclude that a particular experience group perceives rainfall risk significantly more or less strongly than another. The significant omnibus results indicate overall heterogeneity in perceptions, but the specific source of that variation could not be established with sufficient statistical confidence. The particularly small more-than-20-years category is an important limitation when interpreting these findings. Only three respondents belonged to this group, compared with 40 respondents with 1–5 years and 53 with 6–10 years of experience. The descriptive tendency for very experienced respondents to record lower scores may therefore reflect characteristics of a very small subgroup rather than a stable pattern among senior practitioners. Future studies should deliberately recruit larger numbers of highly experienced personnel before drawing stronger conclusions regarding experience-related differences. Taken together, the practitioner-characteristic analyses suggest that rainfall-related safety perceptions are largely shared across respondents, although some overall variation occurs according to age and work experience. Importantly, the absence of consistent significant pairwise differences suggests that rainy-weather safety management should not be designed exclusively around one demographic group. Site-wide procedures, communication systems and weather-response protocols remain appropriate because the identified hazards were broadly recognised across the sample.

Practical implications

The findings have several implications for construction-site safety management. First, the non-significant Friedman result suggests that rainfall-responsive risk assessments should not be limited to only the highest-ranked hazards. A rainy-weather checklist should cover both SEPH and OHFH dimensions because respondents regarded hazards across both domains as important. For SEPH, site management should place emphasis on the condition of walkways, scaffolds and working surfaces; ground stability; drainage and flooding; safe work at height; and appropriate wet-weather protective equipment. These controls are particularly relevant because

rainfall can change otherwise manageable surfaces and temporary ground conditions into more hazardous working environments. Existing literature also notes that weather, terrain and working surfaces contribute to slip and fall events and that rainfall can affect the stability and accessibility of temporary site areas. For OHFH, attention should extend to visibility, temporary electrical systems, equipment performance, worker alertness and communication. These issues indicate the need for operational controls such as weather-responsive work sequencing, inspection of electrical connections and machinery, clear communication arrangements, suitable supervision and predefined criteria for slowing or suspending work when conditions deteriorate. The findings are also relevant to Malaysia's increasingly proactive construction-safety framework. The Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 emphasise responsibilities across project stakeholders and proactive risk management. Incorporating rainfall-responsive controls into planning, risk assessment and site coordination is therefore consistent with a preventive rather than purely reactive approach to construction safety.

Limitations and directions for future research

Several limitations should be considered. First, the study was based on practitioners' perceptions rather than observed accident frequencies or longitudinal site records. High perceived hazard ratings should therefore not be interpreted as evidence that the corresponding hazards necessarily produce higher accident rates. Practitioner perceptions are useful for identifying operational concerns and conditions that may not appear in formal accident databases, but they represent a different form of evidence from actual injury or incident records. Second, the study used a cross-sectional design with 128 respondents. Although the sample was sufficient for the exploratory analyses undertaken, several demographic categories contained very small numbers of respondents, particularly those aged 55 years and above and those with more than 20 years of experience. This limits the precision of subgroup comparisons. Third, the two-factor solution was developed using EFA within a single sample. Future research should validate the SEPH and OHFH structure using an independent sample and confirmatory factor analysis. Additional rainfall-related indicators could also be developed to provide broader coverage of each dimension. Fourth, subsequent research could combine practitioner perceptions with objective information such as rainfall intensity, accident and near-miss reports, site drainage conditions, work suspension records and activity type. Such integration would help determine whether the perceived hazard dimensions are associated with measurable safety outcomes. Finally, future research should examine whether project characteristics—such as project type, project size, construction stage, location and exposure to different monsoon conditions—affect rainfall-related safety perceptions and outcomes. This would extend the present practitioner-focused findings towards more context-sensitive rainy-weather safety management.

CONCLUSION

This study investigated rainfall-related construction safety hazards in Malaysia by examining their perceived importance, underlying dimensional structure and variation across selected practitioner characteristics. The findings show that rainfall should not be conceptualised as a single isolated construction hazard. Instead, rainy conditions interact with a broad range of physical, operational and human-related safety concerns. All ten rainfall-related hazards received relatively high mean ratings. Poor communication and reduced coordination recorded the highest descriptive score, while reduced visibility recorded the lowest; however, the Friedman test showed that the differences among the ten hazards were not statistically significant. This indicates that practitioners generally regarded the assessed rainfall-related hazards as similarly important and supports the use of comprehensive rather than narrowly prioritised rainy-weather safety controls. The EFA provided the principal contribution of the study by identifying two related but distinguishable dimensions: Site Exposure and Physical Hazards (SEPH) and Operational and Human-Factor Hazards (OHFH). SEPH captured hazards relating to slippery surfaces, unstable ground, work at height, flooding and inadequate rainy-condition PPE, whereas OHFH represented visibility, electrical hazards, machinery performance, worker alertness and communication or coordination. Both dimensions demonstrated strong internal consistency, and their positive correlation indicates that physical and operational and human concerns tend to occur as interconnected aspects of rainfall-related construction safety. The practitioner comparisons further showed that gender was not associated with significant differences in either dimension. Age showed an overall difference for OHFH but not SEPH, while work experience showed significant omnibus differences for both dimensions using the Kruskal-Wallis test. However,

adjusted post-hoc comparisons did not establish significant differences between specific groups. These results therefore suggest some variation according to practitioner background but do not support strong conclusions that particular demographic or experience groups consistently perceive rainfall-related hazards more strongly than others. The findings contribute to construction-safety research by moving beyond the conventional ranking of individual rainfall hazards and providing a structured two-dimensional framework for understanding rainy-weather safety. Practically, the results suggest that construction organisations should integrate physical site controls with operational and human-factor measures, including drainage and access management, work-at-height precautions, electrical and machinery inspections, appropriate PPE, communication systems, worker monitoring and weather-contingent work planning. In conclusion, effective rainy-weather safety management requires rainfall to be treated as a condition that can intensify and connect existing construction hazards, rather than merely as a cause of delay or lost productivity. A coordinated approach addressing both SEPH and OHFH can provide a more systematic basis for site risk assessment, preventive planning and safety decision-making under Malaysia's recurrent rainy conditions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Al Refaie, A. M., Alashwal, A. M., Abdul-Samad, Z., & Salleh, H. (2021). Weather and labor productivity in construction: a literature review and taxonomy of studies. *International Journal of Productivity and Performance Management*, 70(4), 941–957. <https://doi.org/10.1108/IJPPM-12-2019-0577>
2. Baek, S., & Choi, E. H. (2026). Climate change health risks and workplace protective strategies for construction workers. *Scientific Reports*, 16(1), 1–16. <https://doi.org/10.1038/s41598-025-33471-z>
3. Chi, C. F., Yang, C. C., & Chen, Z. L. (2009). In-depth accident analysis of electrical fatalities in the construction industry. *International Journal of Industrial Ergonomics*, 39(4), 635–644. <https://doi.org/10.1016/j.ergon.2007.12.003>
4. DOSM. (2024). BIG DATA ANALYTICS : NATIONAL OCCUPATIONAL INJURY AND DISEASE STATISTICS. DOSM. <https://www.dosm.gov.my/portal-main/release-content/big-data-analytics-national-occupational-injury-and-disease-statistics->
5. Ferrari, G. N., Leal, G. C. L., Thom De Souza, R. C., & Galdamez, E. V. C. (2022). Impact of climate change on occupational health and safety: A review of methodological approaches. *Work*, 74(2), 485–499. <https://doi.org/10.3233/WOR-211303>
6. Jaafar, M. H., Arifin, K., Aiyub, K., Razman, M. R., Ishak, M. I. S., & Samsurijan, M. S. (2018). Occupational safety and health management in the construction industry: a review. *International Journal of Occupational Safety and Ergonomics*, 24(4), 493–506. <https://doi.org/10.1080/10803548.2017.1366129>
7. Liao, C. W., & Perng, Y. H. (2008). Data mining for occupational injuries in the Taiwan construction industry. *Safety Science*, 46(7), 1091–1102. <https://doi.org/10.1016/j.ssci.2007.04.007>
8. Lipscomb, H. J., Glazner, J. E., Bondy, J., Guarini, K., & Lezotte, D. (2006). Injuries from slips and trips in construction. *Applied Ergonomics*, 37(3), 267–274. <https://doi.org/10.1016/j.apergo.2005.07.008>
9. Manzoor, B., Othman, I., & Manzoor, M. (2021). Evaluating the critical safety factors causing accidents in high-rise building projects. *Ain Shams Engineering Journal*, 12(3), 2485–2492. <https://doi.org/10.1016/j.asej.2020.11.025>
10. METMalaysia. (2026). Malaysian Meteorological Department. MET Malaysia, 1–2.
11. Mohammadi, A., Tavakolan, M., & Khosravi, Y. (2018). Factors influencing safety performance on construction projects: A review. *Safety Science*, 109(October 2016), 382–397. <https://doi.org/10.1016/j.ssci.2018.06.017>
12. Mohd Azmi, W. F. W., & Misnan, M. S. (2026). Systematic Literature Review on Integrating Design Safety Principles with Climate Change Resilience in the Construction Industry. *IOP Conference Series: Earth and Environmental Science*, 1619(1), 012007. <https://doi.org/10.1088/1755-1315/1619/1/012007>

13. NIOSH. (2026). Construction Falls: Progress and Prevention. NIOSH Science Bulletin. <https://www.cdc.gov/niosh/bulletin/2026/falls-stand-down-2026.html>
14. Schwatka, N. V, Hecker, S., & Goldenhar, L. M. (2016). Defining and Measuring Safety Climate : A Review of the Construction Industry Literature. *Annals of Occupational Hygiene*, i, 1–14. <https://doi.org/10.1093/annhyg/mew020>
15. Waqar, A., Othman, I., Shafiq, N., & Mansoor, M. S. (2024). Evaluating the critical safety factors causing accidents in downstream oil and gas construction projects in Malaysia. *Ain Shams Engineering Journal*, 15(1), 102300. <https://doi.org/10.1016/j.asej.2023.102300>