Construction Operations under Rainy Conditions in Malaysia: An Exploratory Factor Analysis of Rainfall-Related Site Conditions

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ABSTRACT

Rainfall is a recurrent operational constraint in tropical construction, yet limited evidence explains how practitioners perceive the site-level conditions through which rainfall affects day-to-day operations. This study examined rainfall-related construction-site conditions among 128 construction practitioners in Malaysia using a quantitative cross-sectional survey. Eight items were analysed using descriptive statistics, exploratory factor analysis (EFA), reliability analysis, and group comparisons. Mean scores ranged from 3.86 to 4.03, with interruption to daily construction activities rated highest, followed by prolonged rainfall effects and reduced site visibility. The data were suitable for EFA (KMO = 0.872; Bartlett's $\chi^2(28) = 768.79$, $p < .001$). Principal axis factoring indicated a dominant one-factor solution that accounted for 60.75% of the variance after extraction, with loadings ranging from 0.739 to 0.847. The resulting Rainfall-Related Construction Site Conditions (RCSC) measure demonstrated high internal consistency (Cronbach's $\alpha = 0.924$). RCSC scores differed significantly across age, work experience, and education groups, whereas differences by gender and occupational role were not statistically significant. These findings suggest that practitioners experience rainfall occurrence, operational disruption, deteriorating site conditions, and drainage provision as closely interconnected elements of construction operations. The study provides exploratory evidence for a broader RCSC construct and underscores the need for rainfall-responsive scheduling, flexible activity sequencing, drainage management, and site preparedness in tropical construction.

Keywords: rainfall; construction operations; site conditions; operational disruption; exploratory factor analysis; tropical construction; Malaysia

INTRODUCTION

Construction activities are inherently exposed to environmental conditions because a substantial proportion of site operations is undertaken outdoors. Rainfall is particularly important because it can restrict activity feasibility, reduce productivity, interrupt planned work sequences, and increase scheduling uncertainty. Previous research shows that adverse weather can affect construction productivity and project duration, although the magnitude of these effects varies by activity type, project stage, location, and weather intensity (Ballesteros-Pérez et al., 2017; Schuldt et al., 2021). Recent evidence from Vietnamese building projects similarly indicates substantially greater schedule disruption during rainy than dry periods, particularly for underground and structural works that remain directly exposed to weather (Khanh, 2026). Rainfall should therefore be treated not merely as an occasional external disturbance, but as an operational constraint that requires explicit consideration in construction planning and site management. The effects of rainfall extend beyond the immediate loss of working time. Rain can reduce site accessibility and workability, disrupt the movement of workers and equipment, constrain material handling, impair visibility, and alter surface and ground conditions. Excavation, earthworks, concreting, foundation construction, transportation, and other open-site operations are particularly sensitive to wet or waterlogged conditions. Weather-aware construction research therefore emphasises the incorporation of climatic conditions into activity-duration estimates, resource allocation, and project scheduling (Ballesteros-Pérez et al., 2017; Schuldt et al., 2021). Khanh (2026) further showed that heavy rainfall can disrupt excavation and concrete placement and create muddy site conditions and drainage problems, reinforcing the importance of seasonal planning, drainage provision, and flexible work sequencing.

The issue is especially relevant in tropical countries such as Malaysia, where rainfall represents a recurring site condition rather than an exceptional occurrence. According to the Malaysian Meteorological Department (METMalaysia, 2026), Malaysia's equatorial climate is characterised by high humidity and abundant rainfall, with rainfall distribution influenced by seasonal monsoon patterns and local topography. The Northeast Monsoon, in particular, produces periods of heavy rainfall in exposed areas of the east coast of Peninsular Malaysia, western Sarawak, and northeastern Sabah, while other parts of Peninsular Malaysia experience seasonal rainfall maxima commonly associated with the inter-monsoon periods. Consequently, construction projects operating in Malaysia may be exposed to rainfall of different frequencies, intensities, and durations throughout their construction periods. The recurrent nature of such exposure suggests that effective construction planning in Malaysia requires not only allowances for rain days but also an understanding of how rainfall translates into disruptions at the operational and site levels. Evidence from Malaysia further demonstrates the importance of considering weather in construction-performance studies. Using actual labour-productivity and meteorological data from a Malaysian high-rise project, Al-Refaie et al. (2023) found that weather-productivity models developed largely for non-tropical climates had limited predictive accuracy under tropical conditions. Their findings underline the context-specific nature of weather effects and the need for research that reflects tropical climatic and operational characteristics. More broadly, Al Refaie et al. (2021) showed that tropical countries remain comparatively underrepresented in construction weather-productivity research, despite potentially substantial differences in environmental exposure from temperate regions.

Despite growing research on weather-related construction performance, the literature has concentrated mainly on measurable outcomes such as productivity loss, activity duration, schedule delay, weather forecasting, and weather-related claims (Ballesteros-Pérez et al., 2017; Schuldt et al., 2021). Less attention has been directed towards the combination of rainfall characteristics and site-level conditions through which practitioners experience operational disruption. Similar levels of rainfall exposure may not produce equivalent consequences across sites because disruption also depends on rainfall intensity and unpredictability, work interruption, visibility, ground deterioration, drainage, and other preparedness measures. A practitioner-based assessment of these conditions can therefore complement meteorological and productivity records by capturing how rainfall is experienced in day-to-day construction operations. This distinction is important because rainfall measurements alone do not indicate whether a particular site experienced serious work interruption, poor visibility, unstable ground, or inadequate drainage.

Schuldt et al. (2021) showed that weather-related construction research has predominantly focused on task feasibility, modelling, productivity, and mitigation, while tropical studies have often concentrated on meteorological variables and labour productivity (Al-Refaie et al., 2023). Practitioner assessments can provide complementary evidence on recurring operational conditions that may not be systematically recorded in project databases and can therefore inform more practical rainfall-responsive management strategies. Accordingly, this study examines rainfall-related construction-site conditions in Malaysia from the perspective of construction practitioners.

Specifically, it aims to (1) assess practitioners' perceptions of rainfall-related conditions affecting construction operations; (2) identify the underlying factor structure of these conditions and evaluate the internal consistency of the resulting measure; and (3) determine whether RCSC perceptions differ across selected practitioner characteristics. By moving beyond simple factor ranking, the study examines whether rainfall-related indicators form a coherent empirical structure and how perceptions of this broader site-level operational phenomenon vary across practitioner groups. The findings are intended to support more context-sensitive and rainfall-responsive construction planning in tropical environments.

LITERATURE REVIEW

Weather sensitivity of construction operations

Construction differs from many industrial production environments because a substantial proportion of work is performed outdoors, where production systems are directly exposed to precipitation, temperature, wind, and other environmental conditions. Weather has therefore long been recognised as a source of variability in labour productivity, activity duration, and construction scheduling. However, the literature conceptualises weather effects in different ways: as productivity factors, scheduling uncertainties, grounds for extension-of-time claims, or external project risks. This distinction matters because site-level operational mechanisms can be obscured when weather is reduced to a single productivity-loss coefficient or a count of non-working days. Schuldt et al. (2021) provide one of the broadest assessments of this literature. Their systematic review identified precipitation, extreme temperatures, and high winds as major weather conditions affecting labour productivity, equipment operation, material performance, and project scheduling. The review also revealed substantial fragmentation across project types, climatic regions, and modelling approaches, limiting the direct transferability of findings between contexts. A rainfall threshold that renders earthworks unproductive at one site, for example, may not have the same effect at another site with different soil conditions, drainage, equipment, or sequencing. Thus, although adverse weather clearly affects construction performance, greater uncertainty remains about how environmental exposure translates into operational disruption under different site conditions. A similar limitation is evident in weather-productivity research. Through a review and taxonomy of studies published between 2014 and 2019, Al Refaie et al. (2021) identified research clusters relating to weather factors, seasons, worker conditions, work time, health, and productivity management, while highlighting the need for greater attention to tropical environments. Although this literature has generated substantial knowledge about weather-related productivity effects, its dominant emphasis remains on quantifying output and duration. Such an emphasis may be too narrow for understanding site-level conditions such as workflow interruption, reduced visibility, deteriorating ground conditions, and inadequate drainage that occur before they are translated into measurable productivity losses. This distinction suggests that the study of weather effects should extend beyond the question of how much productivity is lost. Equally important is understanding what characteristics of rainfall and site conditions make construction activities vulnerable to interruption. Such an approach shifts attention from weather as an isolated external variable towards the interaction between weather exposure and the operational characteristics of construction sites.

Rainfall as a source of construction disruption

Among weather variables, rainfall is particularly relevant to construction because its effects are both direct and indirect. Direct effects include suspension of outdoor work, while indirect effects may continue after rainfall has stopped through saturated soil, waterlogged access routes, ponding and reduced ground workability. The distinction between direct rainfall duration and its lingering operational consequences is therefore important. A project may experience only several hours of precipitation but lose substantially more productive time if site conditions remain unsuitable afterwards. El-Rayes and Moselhi (2001) demonstrated this problem in highway construction through a decision-support approach for estimating rainfall effects on earthmoving, base-course construction, drainage layers, and paving. Heavy rainfall was particularly problematic because saturated and unworkable soil could result in complete suspension of operations. Importantly, the study moved beyond counting rain days by recognising that different operations have different sensitivities to rainfall. Its highway-specific context, however, limits direct generalisation to building, structural, and other construction operations, reinforcing the need to interpret rainfall impacts in relation to activity and site characteristics. Pan (2005) similarly modelled the productivity and duration of highway construction activities under rainfall uncertainty. Such quantitative approaches improve on simple factor-ranking studies because they connect rainfall with construction outcomes, but they depend on assumptions about rainfall thresholds, activity sensitivity, and historical weather patterns. They are therefore useful for prediction but provide less direct evidence about the site-level mechanisms through which practitioners experience rainfall disruption. Two sites exposed to similar precipitation, for example, may respond differently because of drainage, access, temporary works, and sequencing arrangements.

The importance of context is further supported by Larsson and Rudberg (2023). In a questionnaire study of 232 experienced Swedish construction practitioners, precipitation was rated as more important than wind and temperature in affecting concrete-work productivity, while the estimated productivity reduction varied substantially by weather type, intensity, and task. This variation challenges the use of a single generic productivity reduction for rainfall and highlights the risk of masking activity-specific responses when weather-productivity relationships are reported only at an aggregate level. The variation reported across studies is analytically important. Rather than indicating inconsistency in the literature, it suggests that rainfall effects are conditional. Rain intensity alone does not determine the degree of construction disruption. Activity type, site characteristics, project stage and management response potentially modify the effect. This interpretation provides stronger justification for examining rainfall exposure together with indicators of operational vulnerability rather than ranking rainfall characteristics in isolation.

Rainfall, project scheduling and operational continuity

A second stream of research examines weather primarily from a scheduling perspective. Nguyen et al. (2010) showed that adverse-weather delay analysis is complicated by the definition of normal weather, activity-specific thresholds, lingering effects, lost productivity, and the distinction between working and calendar days. Their work demonstrates that meteorological records alone cannot determine whether a rainfall event actually delays a project; the analysis must also consider whether weather-sensitive activities were scheduled, whether critical work was affected, and whether site conditions remained unsuitable after rainfall ceased. Ballesteros-Pérez et al. (2017) extended this logic through a weather-aware planning tool that incorporated adverse weather into construction scheduling and productivity planning. Their work illustrates the value of integrating climatic information into project programmes rather than using weather only as a retrospective explanation for delay. Nevertheless, weather-informed schedules still require an accurate understanding of activity and site sensitivity. Historical rainfall probabilities can estimate exposure but cannot, by themselves, determine whether a specific site will experience poor visibility, unstable ground, drainage problems, or severe work interruption. Recent evidence reinforces this distinction. Khanh (2026) analysed historical meteorological data and records from 15 completed building projects in Vietnam and developed regression-based models for estimating weather-related schedule delay. Extreme precipitation emerged as an important source of disruption, particularly during structural construction. Although the use of actual project and meteorological records strengthens the evidence base, the principal outcome remained schedule delay; the intermediate site conditions through which rainfall disrupts operations were not the central analytical focus. Taken together, scheduling studies provide convincing evidence that rainfall should be anticipated during project planning. However, they predominantly treat work stoppage, delay or productivity reduction as the end point of weather exposure. This creates an intermediate conceptual gap. The processes through which rainfall affects everyday site operations—such as reduced visibility, deteriorating access, unstable surfaces and persistent wet conditions—remain comparatively less integrated within these models. Understanding these intermediate conditions is important because management intervention is generally implemented at site level before project-level delay becomes observable.

Tropical construction and the Malaysian context

The geographical transferability of weather-productivity findings presents a further challenge. A substantial proportion of construction-weather research has historically been conducted in temperate, cold or seasonally distinct climates. This creates potential problems when models or assumptions are applied to tropical environments characterised by different combinations of rainfall, humidity and temperature. Al Refaie et al. (2021) specifically identified tropical countries as requiring greater research attention within the construction weather-productivity literature. This concern is particularly relevant to Malaysia. METMalaysia (2026) describes the country as being influenced by the Northeast and Southwest Monsoons, with substantial spatial and seasonal variation in rainfall. The Northeast Monsoon can bring particularly heavy rainfall to the east coast of Peninsular Malaysia and parts of Sarawak and Sabah, while other regions experience different seasonal rainfall maxima. Malaysian construction sites therefore operate in an environment where rainfall is not merely an exceptional disturbance but a recurrent operational condition. Empirical research has also questioned whether weather-productivity models developed elsewhere can adequately represent Malaysian construction. Al-Refaie et al. (2023) tested five existing models using actual productivity data from a Malaysian high-rise project together with meteorological observations. Although the USACE model performed better than the other models assessed, its predictive accuracy was only approximately 57%, leading the authors to argue for models better suited to tropical conditions. This finding suggests that the challenge is not simply the availability of weather data; relationships derived in other climatic settings may themselves be inappropriate when transferred directly to Malaysian construction. Nevertheless, the Malaysian study also illustrates a limitation in the current evidence base. Because it was based on actual productivity from a particular high-rise project, its methodological strength in objective measurement is accompanied by limited breadth in representing different construction-site experiences. Objective productivity studies and practitioner surveys should therefore not be regarded as competing methods. Rather, they address different aspects of the same problem. Meteorological and productivity records provide stronger evidence of measurable performance outcomes, whereas practitioner assessments can capture recurrent operational conditions that may not be recorded systematically in project databases. This distinction is particularly important for variables such as sudden downpours, reduced visibility, slippery or unstable ground and drainage adequacy. A meteorological station can provide rainfall intensity and duration, but it cannot indicate whether the drainage arrangement at a particular construction site was adequate or whether the rainfall materially disrupted site movement. Hence, a practitioner-based study can contribute complementary evidence by examining how rainfall conditions are translated into site-level operational vulnerability.

From rainfall exposure to operational vulnerability

A central limitation across much of the literature is the tendency to equate exposure to adverse weather with its resulting impact. Broader climate-risk research distinguishes exposure from vulnerability: being exposed to a climatic hazard does not necessarily produce the same consequence across all systems because vulnerability and capacity to cope vary between contexts. Applied to construction, this means that two sites exposed to similar rainfall intensity may experience different operational outcomes. Drainage illustrates this distinction. Schuldt et al. (2021) noted that rainfall increases soil moisture and that runoff may rapidly affect sites where drainage or protection is inadequate. Drainage therefore represents more than an engineering service during construction; it can influence how effectively a site absorbs and recovers from rainfall. Work sequencing, temporary access, ground preparation, and weather-responsive scheduling may similarly determine whether a rainfall event results in minor inconvenience or substantial operational interruption. Accordingly, rainfall exposure and operational vulnerability should not automatically be treated as the same construct. Rainfall frequency, intensity and sudden occurrence describe characteristics of environmental exposure. In contrast, interruption to activities, impaired visibility and deterioration of ground conditions represent potential manifestations of operational vulnerability. Drainage provision can further be interpreted as an element of site preparedness or adaptive capacity rather than another adverse rainfall effect. This distinction is important statistically as well as conceptually. Combining all such variables into a single undifferentiated index could conceal meaningful underlying dimensions. Existing construction studies provide partial support for this multidimensional interpretation but have rarely tested it explicitly. Larsson and Rudberg (2023) showed that precipitation effects vary by intensity and task, while El-Rayes and Moselhi (2001) demonstrated that activity characteristics influence rainfall-related productivity loss. Weather-aware scheduling studies likewise acknowledge variation among activities and climatic conditions. However, these studies generally begin with predefined activities or weather-response relationships rather than testing whether practitioners' assessments of rainfall frequency, intensity, disruption, visibility, ground condition, and site preparedness form empirically distinguishable dimensions.

Research gap and conceptual direction

The literature therefore supports three broad conclusions. First, rainfall can substantially disrupt weather-sensitive outdoor construction activities. Second, the magnitude of disruption is context dependent and varies with rainfall characteristics, activity type, site conditions, and management response. Third, construction-weather research has concentrated largely on productivity loss, schedule delay, and predictive modelling. What remains less developed is practitioner-based evidence on whether rainfall exposure, operational disruption, changing site conditions, and preparedness are experienced as empirically distinguishable or closely interconnected dimensions in tropical construction. This gap cannot be addressed by another ranking of rainfall-related factors alone. Rankings indicate which conditions practitioners regard as prominent, but they do not establish whether apparently different indicators share an underlying structure. Conversely, combining all rainfall-related variables into a single score without testing dimensionality assumes unidimensionality. The literature therefore points to the need for an exploratory assessment that allows the empirical structure to emerge from the data while retaining the conceptual distinction among exposure, disruption, site condition, and preparedness. Accordingly, the present study examines practitioners' assessments of rainfall frequency and intensity, sudden rainfall, interruption to construction activities, reduced visibility, unstable or slippery ground conditions, and drainage preparedness. Exploratory factor analysis is used to determine whether these indicators form one or more meaningful underlying dimensions, followed by reliability analysis of the retained measure and group comparisons across selected practitioner characteristics. This approach shifts the analytical emphasis from weather as a single exogenous productivity factor towards the broader site-operational conditions through which rainfall is experienced in a tropical construction context.

METHODOLOGY

This study adopted a quantitative cross-sectional survey design to examine rainfall-related construction-site conditions in Malaysia. A structured questionnaire was used to capture practitioners' perceptions and experiences of recurring rainfall-related conditions affecting site operations. The survey design enabled comparable responses to be collected from construction practitioners with direct exposure to site activities under varying weather conditions. The questionnaire comprised demographic information and items relating to rainfall and construction-site conditions.

For the present study, Sections A and B were analysed. Section A collected respondents' professional role, work experience, educational background, age, and gender. Section B comprised eight items (B1–B8) addressing rainfall frequency and intensity, sudden downpours, interruption to construction activities, reduced visibility, slippery or unstable ground conditions, and site drainage preparedness. Responses were measured on a five-point Likert-type scale, with higher scores indicating stronger agreement with each statement. The target respondents were construction practitioners with relevant experience of site-based construction activities.

A total of 128 valid responses were obtained and included in the analysis. Participation was voluntary, respondents were informed that the data would be used solely for research purposes, and responses were treated confidentially and analysed in aggregate form without identifying individual participants. Data were analysed using IBM SPSS Statistics. The dataset was first screened for missing values, coding errors, and response distributions. Frequencies and percentages were used to summarise respondent characteristics, while means and standard deviations described the rainfall-related items. Exploratory factor analysis was then conducted using principal axis factoring. Sampling adequacy was assessed using the Kaiser-Meyer-Olkin (KMO) statistic, Bartlett's Test of Sphericity, individual measures of sampling adequacy, communalities, eigenvalues, the scree plot, factor loadings, and interpretability.

An oblique rotation was planned for use if more than one factor was retained. Cronbach's alpha was used to assess the internal consistency of the retained measure. Group differences in RCSC scores were examined using an independent-samples t-test for gender and one-way analysis of variance for multi-category characteristics. Where homogeneity of variance was violated, Welch's ANOVA and Games-Howell post hoc comparisons were used; Tukey HSD was used when the assumption was satisfied. Statistical significance was evaluated at $p < 0.05$, and effect sizes were reported where available. Factor retention was determined using the eigenvalue pattern, scree-plot inspection, interpretability of the extracted solution, and Horn's parallel analysis. Parallel analysis was conducted using 5,000 raw-data permutations with a 95th-percentile criterion. The permutation approach preserved the observed distributions of the eight questionnaire items. A factor was retained when its observed eigenvalue exceeded the corresponding 95th-percentile eigenvalue generated from the permuted datasets.

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RESULTS AND ANALYSIS

Respondent Profile

Table 1. Profile of Respondents

		N	%
Gender	Male	50	39%
	Female	78	61%
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%
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 and Health Officer (SHO)	16	13%
	Site Safety Supervisor	12	9%
	Construction Worker / Labourer	12	9%
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%
Education level	No formal qualification	5	4%
	SPM / STPM or equivalent	25	20%
	Diploma	26	20%

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	Bachelor's Degree	54	42%
	Master's Degree or above	18	14%

Table 1 presents the demographic characteristics of the respondents (N = 128). In terms of gender, the majority of respondents were female (n = 78, 61%), while 50 respondents (39%) were male. Regarding age, half of the respondents were between 25 and 34 years old (n = 64, 50%), followed by those aged 35–44 years (n = 30, 23%) and 45–54 years (n = 21, 16%). Only a small proportion were below 25 years old (n = 9, 7%) or aged 55 years and above (n = 4, 3%). The respondents represented a range of roles within the construction industry. The largest groups were consultants (n = 17, 13%), site engineers (n = 16, 13%), and Safety and Health Officers (SHO; n = 16, 13%), followed by Department of Occupational Safety and Health (DOSH) officers (n = 15, 12%) and architects (n = 14, 11%). Project managers and site supervisors each accounted for 10% of the sample (n = 13), whereas site safety supervisors and construction workers or labourers each represented 9% (n = 12). The distribution indicates that the sample included respondents from technical, managerial, supervisory, and safety-related positions. With respect to work experience, most respondents had between 6 and 10 years of experience (n = 53, 41%), followed by those with 1–5 years of experience (n = 40, 31%) and 11–20 years of experience (n = 23, 18%). Respondents with less than 1 year of experience represented 7% (n = 9), while only 2% (n = 3) had more than 20 years of experience. Thus, about 72% of the respondents had between 1 and 10 years of construction industry experience, suggesting that the sample was largely composed of practitioners with established exposure to construction-site activities. Regarding educational attainment, the largest proportion of respondents held a bachelor's degree (n = 54, 42%). Diploma holders and respondents with SPM/STPM or equivalent qualifications each accounted for 20% of the sample (n = 26 and n = 25, respectively), while 14% held a master's degree or higher (n = 18). Only 4% reported having no formal qualification (n = 5). Overall, the respondent profile demonstrates a diverse sample in terms of professional role, experience, and educational background, providing perspectives from various levels of construction-site practice.

Descriptive Analysis

Table 2. Perceived Rainfall-Related Conditions Affecting Construction Operations

Rank	Item	M	SD	Agreement, n (%)
1	B3. Rainfall events often cause interruptions to daily construction activities.	4.03	1.01	95 (74.2%)
2	B4. Prolonged rainfall regularly affects site operations and worker safety.	3.99	1.09	96 (75.0%)
3	B6. Rainy conditions reduce visibility on site, affecting workers' ability to perform tasks safely.	3.98	1.15	96 (75.0%)
4	B8. My site has proper drainage systems to manage rainwater runoff during heavy rainfall.	3.95	1.06	90 (70.3%)
5	B2. Rainfall intensity at this site can be classified as moderate to heavy on most rainy days.	3.90	1.16	89 (69.5%)
6	B5. Sudden heavy downpours occur without warning, making it difficult to plan safe work schedules.	3.89	1.17	92 (71.9%)

7	B7. Soil and ground conditions at this site become unstable or slippery after heavy rainfall.	3.89	1.24	91 (71.1%)
8	B1. Heavy rainfall frequently occurs at my construction site during project activities.	3.86	1.17	91 (71.1%)

Table 2 summarises respondents' perceptions of rainfall-related conditions affecting construction operations. All eight items recorded relatively high mean scores (M = 3.86–4.03), indicating broad agreement that rainfall represents a recurring and operationally significant site condition. Interruption to daily construction activities (B3) received the highest rating (M = 4.03, SD = 1.01), with 74.2% of respondents agreeing or strongly agreeing. B3 also had the lowest standard deviation, indicating comparatively consistent perceptions of rainfall-related work interruption. Prolonged rainfall affecting site operations and worker safety (B4; M = 3.99, SD = 1.09) and reduced visibility during rainy conditions (B6; M = 3.98, SD = 1.15) were the next highest-rated items, each with 75.0% agreement. These findings indicate that rainfall is perceived not only as a cause of work stoppage but also as a condition that changes the environment in which construction activities are performed. Site drainage preparedness (B8) ranked fourth (M = 3.95, SD = 1.06), with 70.3% agreement. Unlike B1–B7, B8 is positively framed and represents a management or preparedness condition rather than an adverse rainfall effect. Its high score therefore indicates that many respondents considered their sites adequately equipped to manage runoff, although nearly 30% did not report agreement. Rainfall intensity (B2; M = 3.90, SD = 1.16), sudden heavy downpours that complicate safe work scheduling (B5; M = 3.89, SD = 1.17), and unstable or slippery ground after heavy rainfall (B7; M = 3.89, SD = 1.24) were also rated highly. B7 showed the greatest response dispersion, suggesting greater variation in site-specific experiences of ground deterioration. The comparatively large variation in B7 may reflect differences in project type, soil conditions, drainage provision, site preparation, or the amount of exposed ground. Such site-specific factors may influence the extent to which similar rainfall conditions translate into reduced ground stability or workability. Heavy rainfall frequency (B1) received the lowest mean score (M = 3.86, SD = 1.17), yet 71.1% of respondents still agreed or strongly agreed with the statement. Its lower rank should therefore be interpreted relative to the other highly rated items rather than as evidence that heavy rainfall was unimportant. Overall, operational consequences such as work interruption, prolonged effects on site operations, and reduced visibility were rated slightly higher than the rainfall-exposure indicators themselves. This pattern provides an initial rationale for examining the underlying dimensional structure through EFA rather than inferring it from descriptive rankings alone.

Exploratory Factor Analysis

Table 3. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.872
Bartlett's Test of Sphericity	Approx. Chi-Square	768.792
	df	28
	Sig.	< 0.001

The suitability of the data for EFA was assessed using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. The KMO value of 0.872 indicated very good sampling adequacy, while Bartlett's test was significant, $\chi^2(28) = 768.79$, $p < 0.001$, confirming that the item correlations were sufficiently strong for factor analysis.

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Table 4. Anti-Image Correlation Matrix

Anti-image Matrices		B1	B2	B3	B4	B5	B6	B7	B8
Anti-image Correlation	B1	0.846[a]	-0.112	-0.154	-0.143	-0.394	-0.323	-0.200	0.312
	B2	-0.112	0.912[a]	-0.096	-0.127	-0.113	-0.098	0.150	-0.426
	B3	-0.154	-0.096	0.865[a]	-0.225	-0.270	0.226	-0.416	0.016
	B4	-0.143	-0.127	-0.225	0.910[a]	0.194	-0.271	-0.034	-0.276
	B5	-0.394	-0.113	-0.270	0.194	0.881[a]	0.053	-0.110	-0.188
	B6	-0.323	-0.098	0.226	-0.271	0.053	0.860[a]	0.016	-0.418
	B7	-0.200	0.150	-0.416	-0.034	-0.110	0.016	0.890[a]	-0.280
	B8	0.312	-0.426	0.016	-0.276	-0.188	-0.418	-0.280	0.825[a]

Measures of Sampling Adequacy (MSA)

Individual measures of sampling adequacy, taken from the diagonal of the anti-image correlation matrix, ranged from 0.825 to 0.912. All values were well above the commonly used minimum of 0.50, indicating that each item was adequately represented within the correlation structure. B2 had the highest MSA (0.912) and B8 the lowest (0.825); therefore, no items were excluded on this criterion.

Table 5. Communalities

Item	Initial	Extraction	Decision at this stage
B1	0.643	0.568	Retain
B2	0.670	0.636	Retain
B3	0.655	0.545	Retain
B4	0.681	0.653	Retain
B5	0.627	0.550	Retain
B6	0.699	0.579	Retain
B7	0.657	0.611	Retain
B8	0.793	0.718	Retain
Extraction Method: Principal Axis Factoring.			

Extraction communalities ranged from 0.545 to 0.718, with all eight items exceeding 0.50. B8 had the highest communality (0.718), followed by B4 (0.653) and B2 (0.636), while B3 had the lowest (0.545). These values indicate that each item retained a satisfactory proportion of common variance in the extracted solution.

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Table 6. Factor-retention results from exploratory factor analysis and parallel analysis

Factor	Observed eigenvalue	Variance (%)	95th-percentile random eigenvalue	PA decision
1	5.248	65.604	1.523	Retain
2	0.997	12.468	1.329	Do not retain
3	0.463	5.785	1.200	Do not retain
4	0.401	5.007	1.093	Do not retain
5	0.315	3.941	1.002	Do not retain
6	0.242	3.021	0.921	Do not retain
7	0.200	2.503	0.832	Do not retain
8	0.134	1.671	0.741	Do not retain

Note. Parallel analysis was based on 5,000 raw-data permutations and the 95th-percentile criterion. Factors were retained when the observed eigenvalue exceeded the corresponding random-data eigenvalue.

As shown in Table 6, the first initial eigenvalue was 5.248, accounting for 65.60% of the total item variance. Following principal axis factoring, the retained factor accounted for 60.75% of the variance after extraction. The second observed eigenvalue was .997, which was marginally below the conventional Kaiser criterion of 1.00. Because this value was close to the threshold, parallel analysis was conducted to provide a more robust basis for determining the number of factors to retain. Parallel analysis based on 5,000 raw-data permutations and the 95th-percentile criterion supported retention of a single factor. The first observed eigenvalue (5.248) exceeded the corresponding 95th-percentile random eigenvalue (1.523), whereas the second observed eigenvalue (0.997) was lower than its corresponding random eigenvalue (1.329). All subsequent observed eigenvalues were also below their respective 95th-percentile random eigenvalues. Accordingly, only one factor was retained.

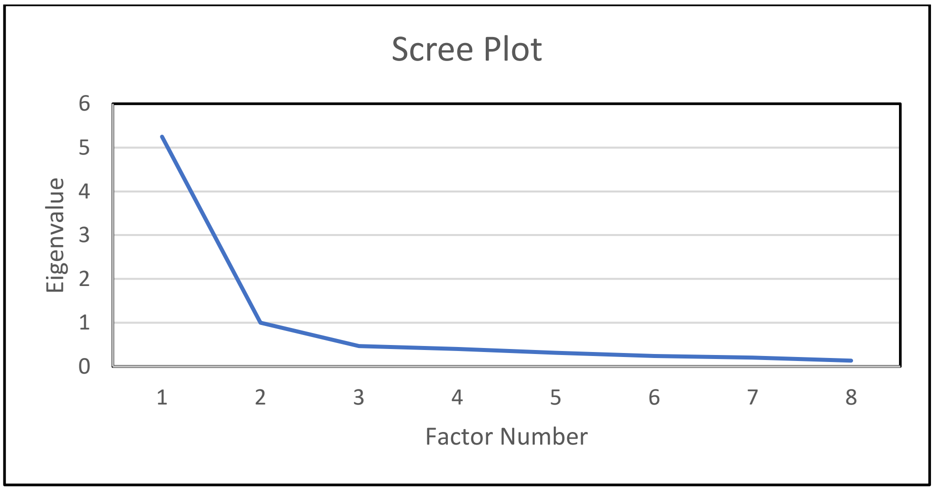

Figure 1. Scree Plot

The scree plot showed a pronounced decline between the first and second eigenvalues, followed by a comparatively flat profile. The inflection after the first factor was consistent with the eigenvalue results and provided additional support for retaining a parsimonious one-factor solution.

Table 7. Factor Matrix

Factor Matrix[a]		
Item	Factor 1	Loading strength
B8	0.847	Very strong
B4	0.808	Very strong
B2	0.798	Strong
B7	0.781	Strong
B6	0.761	Strong
B1	0.754	Strong
B5	0.742	Strong
B3	0.739	Strong
Extraction Method: Principal Axis Factoring.		
One factor was extracted; four iterations were required.		

All eight items loaded strongly on the retained factor, with loadings ranging from 0.739 to 0.847. B8 had the highest loading (0.847), followed by B4 (0.808) and B2 (0.798), while B3 had the lowest loading (0.739). Together with the satisfactory communalities and 60.75% variance explained, these results support a predominantly unidimensional empirical structure for the eight rainfall-related items.

Reliability Analysis

Table 8. Reliability Analysis

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.924	0.925	8

The eight-item RCSC measure demonstrated high internal consistency, Cronbach's α = 0.924; the standardized alpha was similarly high (α = 0.925). These values indicate strong inter-item consistency, although reliability alone does not establish construct validity.

Group Differences

Table 9. Group Differences in RCSC Scores

Characteristic	Test	Result	p	Effect size	Decision
Gender	t-test	t(126) = −1.28	0.203	d = −0.23	Not significant
Age	Welch's ANOVA	F(4, 24.59) = 17.72	< 0.001	η^2 = .151	Significant
Role	ANOVA	F(8, 119) = 1.72	0.101	η^2 = .104	Not significant
Work experience	ANOVA	F(4, 123) = 4.87	0.001	η^2 = .137	Significant
Education	Welch's ANOVA	F(4, 27.06) = 10.71	< .001	η^2 = .157	Significant

Gender was not associated with a statistically significant difference in RCSC scores. Levene's test was not significant, F = 1.49, p = 0.224, supporting the equal-variance assumption. The independent-samples t test showed no significant difference between male and female respondents, t(126) = −1.28, p = 0.203, 95% CI [-0.54, 0.12], with a small effect size (d ≈ -0.23). RCSC scores differed significantly across age groups. Because Levene's test indicated unequal variances, F(4, 123) = 3.35, p = 0.012, Welch's ANOVA was used and was statistically significant, Welch's F(4, 24.59) = 17.72, p < 0.001. Games-Howell comparisons were therefore used to identify the specific group differences. Professional role was not significantly associated with RCSC scores, F(8, 119) = 1.72, p = 0.101, η^2 = .104. The results therefore provide insufficient evidence of systematic differences among the nine occupational groups represented in the sample. Work experience significantly differentiated RCSC scores, F(4, 123) = 4.87, p = 0.001, η^2 = 0.137. Because the homogeneity-of-variance assumption was satisfied, Tukey HSD comparisons were used to identify the specific differences among experience groups. RCSC scores also differed significantly across education groups. Levene's test indicated unequal variances, F(4, 123) = 4.85, p = 0.001; consequently, Welch's ANOVA was used and was statistically significant, Welch's F(4, 27.06) = 10.71, p < 0.001. Games-Howell comparisons were used to identify the specific group differences. In summary, RCSC scores did not differ significantly by gender or occupational role but varied across age, work experience, and education groups. These findings should be interpreted as subgroup differences in reported perceptions rather than as evidence that demographic characteristics independently cause differences in rainfall-related site conditions.

Post Hoc Analysis of Significant Group Differences

Age

Table 10. Games-Howell Post Hoc Comparisons for Age

Age comparison (A2)	Mean difference	95% CI	p	Interpretation
Below 25 vs. 25–34	−1.158	[−2.181, −0.135]	0.025	25–34 scored higher
25–34 vs. ≥55	1.172	[0.705, 1.638]	< 0.001	25–34 scored higher
35–44 vs. ≥55	1.004	[0.487, 1.521]	< 0.001	35–44 scored higher

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RCSC scores differed significantly across age groups. Because homogeneity of variance was violated, Welch's ANOVA and Games-Howell post hoc comparisons were used. Respondents aged 25–34 years reported higher RCSC scores than those below 25 years (mean difference = 1.16, 95% CI [0.14, 2.18], $p = .025$) and those aged 55 years and above (mean difference = 1.17, 95% CI [0.71, 1.64], $p < .001$). Respondents aged 35–44 years also scored higher than those aged 55 years and above (mean difference = 1.00, 95% CI [0.49, 1.52], $p < .001$). No other pairwise differences were statistically significant. These subgroup contrasts should be interpreted cautiously because the oldest age category contained only four respondents.

Table 11. Robust Age-Group Comparison Summary

Characteristic	Test	Statistic	p	Post hoc result
Age (A2)	Welch's ANOVA	Welch's $F(4, 24.59) = 17.72$	< 0.001	Games–Howell: 25–34 > <25; 25–34 > ≥55; 35–44 > ≥55

The age-group pattern was not monotonic: higher RCSC scores were concentrated in the 25–34 and 35–44 year groups relative to selected younger and older categories. The very small number of respondents aged 55 years and above ($n = 4$) limits the stability and generalisability of these comparisons.

Work Experience

Table 12. Descriptive Statistics for RCSC by Work Experience

Work experience (A4)	n	M	SD
Less than 1 year	9	3.36	0.55
1–5 years	40	4.15	0.88
6–10 years	53	4.13	0.83
11–20 years	23	3.48	1.03
More than 20 years	3	2.92	0.44
Overall	128	3.94	0.92

Table 13. Tukey HSD Post Hoc Comparisons for Work Experience

Comparison	Mean difference	95% CI	p	Interpretation
1–5 years vs. 11–20 years	0.663	[0.037, 1.290]	0.032	1–5 years scored higher
6–10 years vs. 11–20 years	0.646	[0.048, 1.244]	0.027	6–10 years scored higher

A one-way ANOVA examined RCSC differences across work experience groups. Levene's test was not significant, $F(4, 123) = 1.91$, $p = 0.114$, supporting the homogeneity-of-variance assumption. RCSC scores differed significantly by work experience, $F(4, 123) = 4.87$, $p = 0.001$, $\eta^2 = .137$. Tukey HSD comparisons showed that respondents with 1–5 years of experience (M = 4.15, SD = 0.88) scored higher than those with 11–20 years (M = 3.48, SD = 1.03), mean difference = 0.66, 95% CI [0.04, 1.29], p = 0.032. Respondents with 6–10 years of experience (M = 4.13, SD = 0.83) also scored higher than those with 11–20 years, mean difference = 0.65, 95% CI [0.05, 1.24], p = 0.027. No other pairwise differences were statistically significant. Practitioners with 1-5 and 6–10 years of experience therefore reported higher RCSC scores than those with 11–20 years of experience. The cross-sectional design does not establish why these differences occurred. The descriptive mean for respondents with more than 20 years of experience was lower, but this subgroup contained only three respondents and none of its pairwise comparisons was statistically significant.

Education Level

Table 14. Descriptive Statistics for RCSC by Education Level

Education level	n	M	SD
No formal qualification	5	2.95	0.40
SPM/STPM or equivalent	25	4.25	0.82
Diploma	26	3.56	1.16
Bachelor’s degree	54	4.19	0.73
Master’s degree or above	18	3.58	0.81
Overall	128	3.94	0.92

The highest mean RCSC score occurred among respondents with SPM/STPM or equivalent qualifications (M = 4.25), followed by those with a bachelor's degree (M = 4.19). Respondents with no formal qualification had the lowest mean (M = 2.95); however, this subgroup contained only five respondents.

Table 15. Games-Howell Post Hoc Comparisons for Education Level

Comparison	Mean difference	95% CI	p	Interpretation
No formal qualification vs. SPM/STPM	−1.30	[−2.07, −0.53]	.001	SPM/STPM group scored higher
No formal qualification vs. Bachelor’s degree	−1.24	[−1.98, −0.49]	.004	Bachelor’s group scored higher

RCSC scores differed significantly across education groups. Because Levene's test indicated unequal variances, $F(4, 123) = 4.85$, $p = 0.001$, Welch's ANOVA and Games-Howell post hoc comparisons were used. Respondents with SPM/STPM or equivalent qualifications (M = 4.25, SD = 0.82) scored higher than those with no formal qualification (M = 2.95, SD = 0.40), mean difference = 1.30, 95% CI [0.53, 2.07], p = 0.001. Respondents with bachelor's degrees (M = 4.19, SD = 0.73) also scored higher than those with no formal qualification, mean difference = 1.24, 95% CI [0.49, 1.98], p = 0.004. No other pairwise differences were significant. The pattern was therefore not linear across educational attainment and should be interpreted cautiously given the very small no-formal-qualification subgroup.

DISCUSSION

Rainfall as a Recurrent Operational Condition in Construction

The findings indicate that rainfall is perceived as a recurrent and operationally important condition on Malaysian construction sites. All eight indicators recorded relatively high mean scores, with work interruption, prolonged rainfall effects, and reduced visibility among the most prominent conditions. This pattern suggests that practitioners experience the significance of rainfall primarily through its consequences for ongoing site operations rather than through rainfall frequency alone. This interpretation is consistent with established construction-weather research. El-Rayes and Moselhi (2001) showed that heavy rainfall can substantially reduce highway-construction productivity and can suspend operations when soil becomes saturated and unworkable. Schuldt et al. (2021) similarly identified precipitation as a major weather condition affecting task feasibility, productivity, equipment, and schedules. More recent evidence from Vietnam indicates particularly strong rainfall effects during underground and structural work, where activities remain directly exposed to wet conditions (Khanh, 2026). The present study extends this evidence by showing how such effects are perceived collectively by practitioners working in a tropical construction environment. The ranking of work interruption (B3) above the rainfall-frequency item (B1) is particularly informative. Although frequent heavy rainfall remained widely acknowledged, operational interruption, prolonged site effects, and visibility problems received slightly higher ratings. For construction managers, the practical significance of rainfall may therefore depend less on rainfall occurrence alone than on whether it prevents work from proceeding, constrains access or visibility, or leaves the site unsuitable for subsequent activities. This interpretation aligns with weather-aware planning research. Ballesteros-Pérez et al. (2017) showed that weather sensitivity varies across activities and can materially alter project duration, while Larsson and Rudberg (2023) found that the effect of precipitation on concrete-work productivity varied substantially by task and weather intensity. The present findings should therefore not be reduced to the general observation that 'rain is important'; rather, they indicate that rainfall becomes operationally consequential through its interaction with specific activities and site conditions.

Intensity, Unpredictability, and Deterioration of Site Conditions

The results for rainfall intensity, sudden downpours, and ground deterioration further show that rainfall-related disruption extends beyond scheduled work stoppage. Moderate-to-heavy rainfall, unpredictable downpours, and unstable or slippery ground were all strongly endorsed, indicating that both severity and unpredictability contribute to operational uncertainty. This distinction has direct implications for planning. Historical average rainfall can support long-term scheduling, but averages cannot fully represent short-duration intense rainfall, sudden downpours, or the persistence of poor ground conditions after rainfall stops. Schuldt et al. (2021) emphasised that weather affects construction through multiple task-feasibility mechanisms, while Khanh (2026) highlighted seasonal planning, drainage provision, and flexible sequencing as responses to rainy-season delay. Rainfall-responsive planning should therefore incorporate both expected seasonal exposure and short-term operational variability. The Malaysian context heightens the relevance of these findings. METMalaysia (2026) characterises the country by abundant rainfall influenced by monsoon regimes and topography, with particularly heavy rainfall in exposed regions during the Northeast Monsoon. Rainfall should therefore be treated as a recurring operational constraint rather than solely as an exceptional or unforeseen event, with implications for scheduling, temporary works, access planning, drainage, and site preparation. The relatively large standard deviation for B7 (SD = 1.24) suggests that rainfall-related ground deterioration may vary substantially across sites. Soil characteristics, grading, project stage, temporary access, drainage, ground treatment, and exposed earthwork can all influence how rainfall affects ground workability. This interpretation is consistent with El-Rayes and Moselhi (2001), who showed that rainfall sensitivity depends strongly on the nature of construction operations and soil workability. Future research should therefore combine practitioner assessments with project-specific variables such as soil type, activity type, drainage capacity, and measured rainfall.

Drainage Preparedness: An Important but Conceptually Distinctive Finding

B8 warrants separate consideration. Overall, 70.3% of respondents agreed or strongly agreed that their sites had proper drainage systems to manage rainfall runoff, with a mean of 3.95. Adequate drainage is an important form of site preparedness, and tropical evidence similarly identifies drainage and flood-prevention measures as practical responses for maintaining site workability during rainy periods (Khanh, 2026). However, B8 differs conceptually from the remaining items. B1–B7 primarily describe rainfall exposure or adverse consequences, whereas B8 describes a positive management provision. This distinction becomes important when interpreting the factor-analysis results. One plausible explanation is that sites exposed to more substantial rainfall-related challenges may also be more likely to have drainage systems in place. In other words, exposure and adaptation can coexist. A site experiencing frequent or operationally consequential rainfall is not necessarily unprepared for it. Indeed, greater exposure may encourage stronger drainage provision. This interpretation would explain why respondents who strongly acknowledged rainfall-related conditions also tended to acknowledge drainage arrangements. Nevertheless, this result creates a conceptual limitation for the composite variable.

The resulting construct should not be interpreted narrowly as an "operational vulnerability" score because a high B8 score signifies greater preparedness rather than greater vulnerability. The broader term Rainfall-Related Construction Site Conditions (RCSC) is therefore more defensible. A high RCSC score indicates stronger acknowledgement of the collection of rainfall-related site conditions represented in the questionnaire, rather than simply greater risk or vulnerability. This distinction is important because statistical coherence does not automatically establish conceptual equivalence. Future questionnaire development should therefore consider measuring rainfall exposure, operational disruption, and rainfall preparedness using separate multi-item constructs. Drainage preparedness, for example, could be expanded beyond one item to include temporary drainage, dewatering arrangements, access maintenance, runoff diversion and inspection procedures. Such refinement would allow future studies to test whether preparedness moderates or reduces the relationship between rainfall exposure and operational disruption.

Underlying Structure of Rainfall-Related Construction-Site Conditions

The EFA showed substantial common variance across B1–B8. The KMO value of .872, significant Bartlett's test, individual MSA values of .825–.912, and communalities of .545–.718 all supported the suitability of the items for factor analysis. No item appeared poorly represented within the common correlation structure. Principal axis factoring identified a dominant first factor with an initial eigenvalue of 5.248; after extraction, this factor explained 60.75% of the variance. The second eigenvalue was .997 and all subsequent eigenvalues were substantially smaller. The scree plot showed a sharp decline after the first factor, and all retained loadings were strong (.739–.847), collectively supporting a parsimonious one-factor interpretation. The one-factor result challenges the initial expectation that practitioners might clearly separate rainfall exposure from operational consequences and preparedness. Instead, respondents appear to experience rainfall characteristics, work interruption, changing ground and visibility conditions, and drainage provision as closely interconnected elements of the same site-operational context.

This may reflect the way rainfall is encountered in practice: not as an abstract meteorological exposure, but as a combined process involving precipitation, altered site conditions, disrupted work, and management response. The one-factor conclusion should nevertheless be interpreted cautiously. Although the second eigenvalue (.997) was very close to the conventional Kaiser threshold of 1.00, factor-retention decisions should not rely on this criterion alone (Fabrigar et al., 1999). In the present study, Horn's (1965) parallel analysis provided a stronger empirical retention criterion and supported the one-factor solution: only the first observed eigenvalue exceeded its corresponding 95th-percentile random eigenvalue. Together with the scree plot and strong first-factor loadings, this supports a predominantly unidimensional statistical structure. However, this evidence demonstrates shared empirical structure rather than proving that rainfall exposure, operational disruption, and preparedness are theoretically identical concepts. This distinction is particularly important because B8 is positively worded and represents site preparedness.

Reliability and Measurement Consistency

The eight-item RCSC measure demonstrated high internal consistency (Cronbach's $\alpha = 0.924$; standardized $\alpha = 0.925$). This strengthens confidence in the coherence of the item set but should not be interpreted as evidence of construct validity by itself. Cronbach's alpha reflects inter-item consistency and is influenced by item number and intercorrelations; a high value does not establish that a scale represents a theoretically pure construct (Tavakol & Dennick, 2011).

This caution is particularly relevant because B8 represents preparedness whereas the other items primarily describe rainfall exposure or adverse operational conditions. Taken together, the EFA and reliability results indicate that B1–B8 behave as a coherent empirical set, but the resulting measure should be interpreted broadly as Rainfall-Related Construction Site Conditions rather than as a pure vulnerability construct. Future confirmatory research should use a new sample and independently developed multi-item measures of rainfall exposure, operational disruption, and preparedness.

Differences According to Practitioner Characteristics

Group comparisons provided a secondary perspective on how RCSC perceptions varied across the sample. Gender was not associated with a significant difference, $t(126) = -1.28$, $p = 0.203$, and occupational role was also not significant, $F(8, 119) = 1.72$, $p = 0.101$. In contrast, significant differences were observed for age using Welch's ANOVA, $F(4, 24.59) = 17.72$, $p < 0.001$; work experience using one-way ANOVA, $F(4, 123) = 4.87$, $p = 0.001$; and education using Welch's ANOVA, $F(4, 27.06) = 10.71$, $p < 0.001$. Post-hoc comparisons showed that the age effect was concentrated in selected contrasts involving the 25–34 and 35–44 year groups, the work experience effect reflected higher scores among respondents with 1-5 and 6–10 years than those with 11–20 years, and the education effect was driven mainly by lower scores in the very small no-formal-qualification group. These findings are broadly consistent with construction-risk research showing that demographic and experiential characteristics can shape safety-related perceptions (Han et al., 2019; Ibrahim et al., 2022), but the construct and context examined here differ and the comparisons should not be treated as directly equivalent evidence. Age, work experience, education, and occupational role are also likely to overlap in practice. Older practitioners generally have greater opportunity to accumulate experience, while qualifications may be associated with professional responsibilities. Separate group comparisons cannot determine whether age, experience, and education exert independent effects. A future multivariable model would be needed to disentangle these correlated characteristics. The subgroup findings require particular caution because several categories were very small: only four respondents were aged 55 years or above, three had more than 20 years of experience, and five reported no formal qualification. These small cells can make group means sensitive to individual observations and limit the robustness and generalisability of the corresponding pairwise comparisons.

Overall Contribution and Practical Implications

Taken together, the results suggest that rainfall-related construction conditions in Malaysia are experienced as an interconnected operational phenomenon rather than as isolated weather variables. Practitioners simultaneously recognised rainfall occurrence, intensity, and unpredictability; interruption to activities; reduced visibility; deteriorating ground conditions; and drainage arrangements. The dominant one-factor structure and high reliability indicate substantial empirical coherence, while the conceptual distinction surrounding B8 cautions against treating all items as theoretically interchangeable. This combination of statistical coherence and conceptual differentiation is a key contribution of the study. The practical implication is that project managers should move beyond generic allowances for 'rain days' and consider the operational pathways through which rainfall affects work. Rainfall-responsive scheduling, flexible sequencing of weather-sensitive activities, short-term weather monitoring, temporary drainage and dewatering, maintenance of access routes and working platforms, and contingency planning should be integrated more systematically into site management. Practitioner surveys can capture accumulated operational experience that rainfall gauges do not directly measure, but they cannot establish actual rainfall intensity, productivity loss, or schedule delay. Future studies should therefore integrate practitioner perceptions with meteorological records, daily site diaries, planned-versus-actual activity durations, productivity records, and project-specific drainage or ground-condition data.

CONCLUSION

This study examined rainfall-related construction-site conditions among 128 construction practitioners in Malaysia. All eight indicators received relatively high ratings, with interruption to daily construction activities, prolonged rainfall effects, and reduced site visibility among the most prominent conditions. The findings show that the practical significance of rainfall lies not only in its frequency or intensity but also in the operational consequences and site-management responses that accompany it. Exploratory factor analysis supported a predominantly unidimensional empirical structure: the retained factor accounted for 60.75% of the variance after extraction, item loadings ranged from 0.739 to 0.847, and the RCSC measure demonstrated high internal consistency (Cronbach's $\alpha = 0.924$). These results suggest that practitioners perceive rainfall exposure, operational disruption, changing site conditions, and drainage provision as closely interconnected aspects of a broader construction-site experience. Because drainage preparedness is conceptually different from adverse rainfall effects, however, the RCSC measure should not be interpreted narrowly as a vulnerability score. RCSC perceptions differed across selected age, work experience, and education groups, while gender and occupational role differences were not statistically significant. These subgroup findings are exploratory and should be interpreted cautiously because several categories contained very small numbers of respondents and the demographic characteristics may overlap. For tropical construction practice, the findings support treating rainfall as a routine planning consideration rather than an occasional disruption. Rainfall-responsive scheduling, flexible activity sequencing, effective drainage and dewatering, access maintenance, and short-term weather monitoring should be incorporated systematically into site planning. The study is limited by its cross-sectional, perception-based design, modest sample size, and absence of objective meteorological, productivity, and delay records. Future research should validate the RCSC structure using larger and more balanced samples, conduct confirmatory factor analysis using an independent sample, and integrate practitioner perceptions with measured rainfall and project-performance data.

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.

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