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Delphi-Based Prioritization of Climate and Weather-Related Risks and Their Time-Cost-Quality-Safety Effects on Public Infrastructure Projects in Leyte, Philippines

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Abstract

Climate and weather-related hazards pose significant challenges to infrastructure project implementation in Leyte Province, Philippines, where typhoons, heavy rainfall, flooding, landslides, and coastal hazards can disrupt construction activities and affect project performance. This study aimed to identify, assess, and prioritize climate and weather-related risks affecting public infrastructure projects in Leyte Province and to determine their effects on project time, cost, quality, and safety. A three-round Delphi study was conducted with 18 infrastructure professionals, all of whom participated in each round. Round 1 focused on risk identification, while Rounds 2 and 3 assessed and validated the frequency and severity of the identified risks using a five-point Likert scale. Frequency Index, Severity Index, and Importance Index were used to assess and prioritize the risks, while Pareto Analysis was applied to determine their cumulative contribution to the overall risk profile. The Kruskal–Wallis test was used to examine differences in expert assessments across selected respondent characteristics. The study identified 49 climate and weather-related risks grouped into seven themes. The three highest-ranked risks were disruption of project logistics and material delivery during typhoon events (II = 0.693), delay or suspension of construction activities due to typhoon events (II = 0.667), and storm surge impacts on coastal infrastructure (II = 0.604). The TCQS assessment showed that these risks had varying effects on project performance, with logistics disruption having its strongest effects on cost and quality, while typhoon-related work suspension had its strongest effects on time and safety. Overall, the findings demonstrate that climate and weather-related risks should be explicitly considered in public infrastructure planning and construction management in Leyte Province, particularly in prioritizing risks and developing measures to minimize their effects on project performance.

Keywords: Climate and Weather-Related Risks; Infrastructure Projects; Delphi Method; Importance Index; Pareto Analysis

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INTRODUCTION

Climate and weather-related hazards pose significant challenges to infrastructure construction because they can interrupt activities, damage materials and facilities, reduce productivity, and affect project time, cost, quality, and safety. Schuldt et al. (2021) found that adverse weather is a recurring cause of construction delays, while Dong et al. (2025) showed that weather conditions can affect time, cost, and quality in construction projects. These findings indicate that climate and weather-related hazards should be considered as project risks rather than only as environmental conditions.

The Philippines is highly exposed to these hazards. Philippine Atmospheric, Geophysical and Astronomical Services Administration [PAGASA] (2026) reports that approximately 20 tropical cyclones enter the Philippine Area of Responsibility each year, bringing strong winds and heavy rainfall that may result in flooding,

landslides, and storm surges. The Philippine Statistics Authority (2025) also reported 225 small-scale natural hazards nationwide in 2024. These hazards can cause disruptions to infrastructure projects, particularly in areas that experience repeated exposure to extreme weather.

Leyte Province is particularly vulnerable because of its coastal areas, river systems, and mountainous terrain. Previous studies have documented the effects of natural hazards on Philippine infrastructure. Adarne et al. (2023) examined the impacts of natural hazards on road infrastructure in the Philippines, while Hong et al. (2022) documented changes in extreme precipitation in the country. These studies provide important evidence of hazard exposure and infrastructure vulnerability. However, there is limited local research that brings together the different climate and weather-related risks affecting infrastructure construction in Leyte and systematically determines their relative importance based on the assessment of infrastructure professionals. There is also a need to examine how these risks affect the major project-performance dimensions of time, cost, quality, and safety.

This study aimed to identify, assess, and prioritize climate and weather-related risks affecting public infrastructure projects in Leyte Province and determine their effects on project time, cost, quality, and safety (TCQS). Specifically, it sought to: (1) identify the climate and weather-related risks affecting infrastructure projects; (2) assess their frequency and severity based on expert assessment; (3) prioritize the risks using the Frequency Index, Severity Index, Importance Index, and Pareto Analysis; (4) examine differences in expert assessments using the Kruskal–Wallis test; and (5) assess the effects of the priority risks on TCQS. The study provides a localized risk profile that can be used by DPWH district offices, LGUs, contractors, consultants, and other infrastructure stakeholders to identify priority risks and guide appropriate risk-management measures during project planning and implementation.

LITERATURE REVIEW

Climate and weather-related hazards are important sources of risk in construction because many activities are directly exposed to environmental conditions. Adverse weather can interrupt construction work, reduce productivity, damage materials and equipment, restrict site access, and increase project costs. Schuldt et al. (2021) identified adverse weather, particularly precipitation, extreme temperatures, and high winds, as important contributors to construction delays. Dong et al. (2025) further reported that weather conditions can influence project time, cost, quality, and safety.

The risks associated with climate and weather are particularly relevant in the Philippine setting. Adarne et al. (2023) examined the effects of natural hazards on Philippine infrastructure and emphasized the vulnerability of infrastructure to hazard events. Hong et al. (2022) documented extreme precipitation conditions in the Philippines, supporting the consideration of heavy rainfall and flooding in infrastructure risk assessment. Agar (2023) also discussed climate-related risks relevant to infrastructure and construction, with particular focus on the potential effects of changing environmental conditions on project implementation.

Other studies provide a basis for considering specific hazards affecting construction. Lyu et al. (2024) examined the implications of extreme weather conditions for construction activities and worker-related concerns. Pulhin et al. (2022) emphasized the importance of climate adaptation and resilience in reducing vulnerability to climate-related hazards. For infrastructure exposed to coastal conditions, Atienza and Hipolito (2010) discussed the implications of coastal hazards and their potential effects on infrastructure. Reyes (2025, 2026) further addressed climate-related concerns relevant to construction and infrastructure performance.

Climate- and weather-related hazards affect construction directly through physical damage and indirectly through work stoppages, access restrictions, delivery disruptions, and productivity losses. Because one hazard may affect several project-performance dimensions, an integrated risk assessment is necessary.

Risk Assessment and Delphi Method. Construction risk assessment involves identifying potential risks and evaluating their likelihood and consequences to determine their relative importance. Because the occurrence and effects of climate-related hazards may vary according to geographical and project conditions, expert judgment can provide important contextual information. Hallowell and Gambatese (2010) demonstrated the usefulness of structured expert judgment in construction research, particularly for complex issues where empirical information may be limited.

The Delphi method provides a structured approach for obtaining expert judgments through successive rounds of assessment. Sourani and Sohail (2015) discussed the application of Delphi in construction management research for addressing complex issues requiring informed professional judgment. In the present study, the method provides an appropriate means of combining findings from previous literature with the practical experience of infrastructure professionals working within the local context.

Basis of the Initial Risk Inventory. The literature reviewed in this study served as the basis for identifying the initial 31 climate and weather-related risks. These risks were derived from Adarne et al. (2023), Agar (2023), Lyu et al. (2024), Hong et al. (2022), Reyes (2025, 2026), Atienza and Hipolito (2010), and Pulhin et al. (2022). The literature provided coverage of risks associated with typhoons and strong winds, heavy rainfall and flooding, landslides and soil movement, extreme heat and drought, coastal and sea-level-rise hazards, and related construction and management concerns.

The literature-based inventory provides a broad starting point for examining risks relevant to infrastructure construction. However, the occurrence and perceived importance of these risks may differ according to local conditions and professional experience. Thus, the literature-derived risks were subjected to expert assessment through the Delphi process to establish their relevance within the context of infrastructure projects in Leyte.

Research Gap. Previous studies have established the effects of climate and weather-related hazards on construction and infrastructure. However, much of the existing literature addresses individual hazards or specific project impacts, with limited attention to the integrated prioritization of multiple climate and weather-related risks within a localized infrastructure context. In particular, there is limited evidence establishing the relative importance of these risks from infrastructure professionals in Leyte Province.

The present study addresses this gap by combining literature-based risk identification, expert assessment through a three-round Delphi process, and quantitative risk prioritization. It further examines the implications of the identified priority risks for time, cost, quality, and safety (TCQS). This provides a localized basis for understanding which climate and weather-related risks require greater attention in infrastructure project planning and management in Leyte.

METHODOLOGY

Research Design. This study employed a three-round Delphi method to systematically examine climate- and weather-related risks affecting infrastructure projects in Leyte Province, Philippines. The method was selected for its structured approach to eliciting and refining expert judgments through successive rounds of assessment and feedback, making it suitable for investigating complex, context-specific construction risks (Hallowell & Gambatese, 2010).

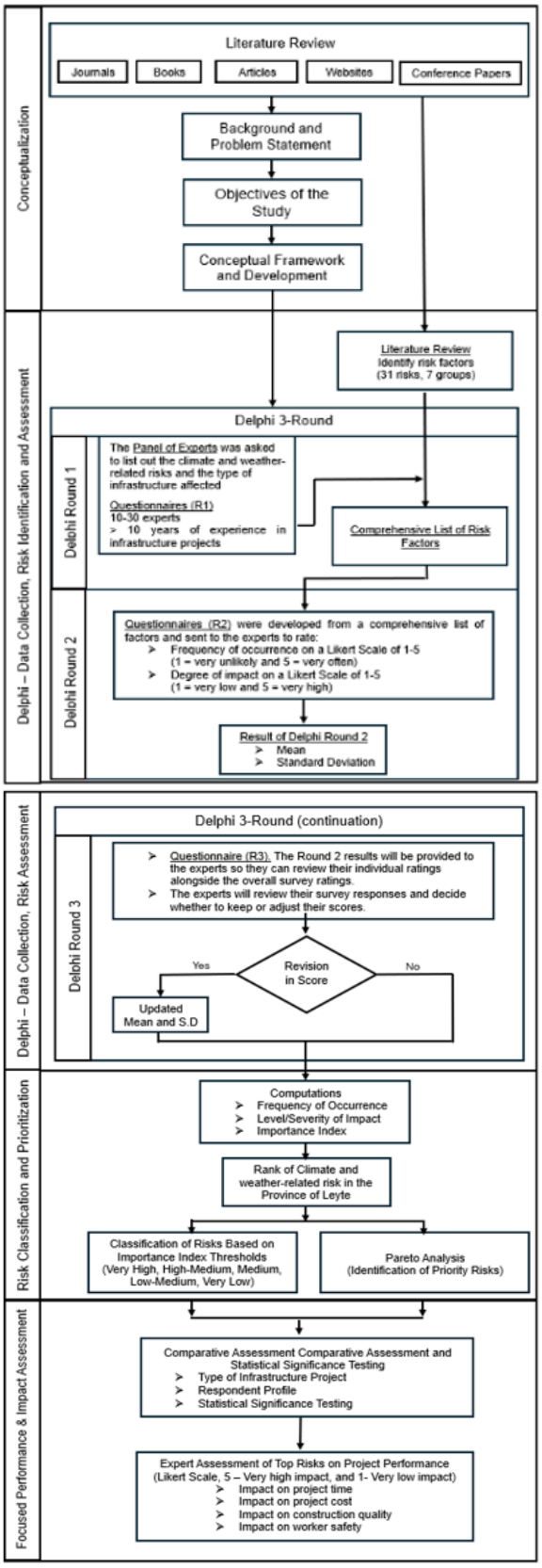


Figure 1
Research Framework of the Study

The research process involved four main stages: literature-based risk identification and expert review in Round 1; quantitative risk assessment in Round 2; reassessment and consensus determination in Round 3; and subsequent risk prioritization and comparative analysis.

Expert Selection and Qualification. A purposive sampling approach was used to select infrastructure professionals with relevant knowledge and experience in infrastructure planning, design, construction, supervision, and implementation in Leyte Province. Twenty-seven (27) experts were initially invited to participate. To ensure sufficient professional exposure to infrastructure and climate- and weather-related risks, participants were required to have at least 10 years of relevant professional experience and direct involvement in infrastructure projects.

Following the screening process, 18 experts qualified and participated in all the Delphi rounds. The remaining invited professionals either did not meet the minimum experience requirement, were unavailable to participate, or did not continue with the succeeding rounds. The final panel of 18 experts was considered adequate for a Delphi study. Hallowell and Gambatese (2010) reported that construction engineering and management Delphi studies commonly use relatively small expert panels and suggested a minimum of eight experts, with panel size determined by the nature of the research and availability of qualified experts.
The experts were drawn from relevant sectors involved in infrastructure development, including government agencies, local government units, consulting, contracting, and academia. The resulting panel provided professional perspectives from different stages of infrastructure project planning and implementation.

Literature-Based Risk Identification. A review of relevant literature was conducted to establish the initial inventory of climate- and weather-related risks affecting infrastructure projects. Thirty-one (31) risks were identified from the

literature and served as the initial risk list for Delphi Round 1.

The sources used to establish the 31 literature-derived risks included Adarne et al. (2023), Agar (2023), Lyu et al. (2024), Hong et al. (2022), Reyes (2025, 2026), Atienza and Hipolito (2010), and Pulhin et al. (2022). The identified risks were organized into seven broad themes covering typhoon and strong wind, heavy rainfall and flooding, landslides and soil movement, extreme heat and drought, coastal and sea-level rise, risk management and policy-related gaps, and community and social adaptation-related risks.

The literature review therefore provided the initial risk pool for the Delphi process, while allowing the expert panel to identify risks that may not have been captured by previous studies.

Delphi Round 1: Risk Review and Identification. Delphi Round 1 was conducted using a blank, open-ended questionnaire to allow the experts to independently identify climate- and weather-related risks affecting infrastructure projects in Leyte Province. The experts were not provided with the literature-derived risk list, allowing responses to be based on their professional experience, knowledge, and observations.

The responses were analyzed through thematic analysis following Braun and Clarke (2006). Similar or overlapping risk statements were coded and consolidated, while distinct and relevant risk concepts were retained. The expert-identified risks were then combined with the 31 risks identified from the literature review to establish the consolidated risk inventory for the succeeding Delphi rounds.

Delphi Round 2: Quantitative Risk Assessment. In Round 2, the consolidated list of risks was presented to the experts for quantitative assessment. Each risk was evaluated according to its frequency of occurrence and severity/level of impact using a five-point Likert scale.

For frequency, the scale ranged from 1 = Very Unlikely to 5 = Very Likely. For severity, the scale ranged from 1 = Very Low to 5 = Very High. The ratings obtained from the experts were used to calculate the Frequency Index (FI), Severity Index (SI), and Importance Index (II).

The use of successive quantitative assessments allowed the experts to evaluate the identified risks using a common rating framework while maintaining the iterative nature of the Delphi process.

Delphi Round 3 and Consensus Assessment. During Round 3, the experts were provided with summarized results from Round 2 and were given an opportunity to review and revise their previous ratings. This process was intended to promote convergence of expert judgment before establishing the final ratings.

Consensus was assessed using the Interquartile Range (IQR), calculated as:

$$IQR = Q_3 - Q_1$$

where $Q_1$is the first quartile and $Q_3$is the third quartile of the expert ratings. An *IQR* of $\leq$1 was adopted as the criterion for consensus. This criterion is consistent with the approach used by Kirschbaum et al. (2019), who adopted *IQR* $\leq$1 as an indicator of consensus for expert ratings using a five-point scale. The authors also noted that Delphi studies do not have a universally accepted consensus criterion and that different studies use different measures and thresholds.

Risk Index Calculation and Prioritization. Following the Delphi assessment, the risks were prioritized using the Frequency Index (FI), Severity Index (SI), and Importance Index (II). The Frequency Index was calculated as:

$$FI = \frac{\sum(a \times n)}{A \times N}$$

where a is the rating assigned, n is the number of experts giving the rating, A is the highest possible rating, and N is the total number of respondents.

The Severity Index was calculated using the same formulation:

$$SI = \frac{\sum(a \times n)}{A \times N}$$

The Importance Index was then calculated as:

$$II = FI \times SI$$

The resulting II values were used to rank the identified risks, with higher values representing greater overall importance.

Table 1
Importance Index Classification

Importance Index	Priority Classification
0.80–1.00	Very High
0.60–0.79	High
0.40–0.59	Moderate
0.20–0.39	Low
0.00–0.19	Very Low

The classification follows the five-level prioritization approach applied in related construction risk research, including the work of Fashina et al. (2021) and Boakye et al. (2023). The classification was applied consistently to the final Importance Index values.

Pareto Analysis. Pareto Analysis was applied to the Importance Index results to identify the risks contributing most substantially to the overall risk profile. The analysis was based on the cumulative contribution of the ranked risk items and the 80/20 principle, which is commonly used to identify a relatively small number of factors responsible for a substantial proportion of an overall effect.

Comparative Statistical Analysis. The Kruskal–Wallis H test was used to determine whether statistically significant differences existed in the experts' risk assessments across the demographic and professional groups examined in the study. The test was selected as a non-parametric method appropriate for comparing independent groups where the data are ordinal or do not satisfy the assumptions of parametric tests (Kruskal & Wallis, 1952).

The statistical analysis was performed using RStudio. The significance level was set at $\alpha = 0.05$. A p-value below 0.05 was interpreted as evidence of a statistically significant difference among the groups.

The specific demographic and professional variables tested were those collected through the expert questionnaire and subsequently reported in the Results and Discussion.

TCQS Impact Assessment. The effects of the priority risks on infrastructure project performance were assessed using the Time-Cost-Quality-Safety (TCQS) framework. The experts assessed the effects of the priority risks on four project-performance dimensions: project time, project cost, construction quality, and worker safety.

Each dimension was evaluated using a five-point Likert scale ranging from 1 = Very Low Impact to 5 = Very High Impact. The assessments were used to determine which aspects of project performance were most affected by the prioritized climate- and weather-related risks.

Ethical Considerations. The study was conducted in accordance with the applicable institutional research ethics requirements. Ethics clearance was granted by the Polytechnic University of the Philippines Open University System University Research Ethics Committee (PUP OUS USREC), under Ethics Clearance No. 0226-0098.

Before participation, all experts were informed of the purpose and procedures of the study and provided informed consent. Participation was voluntary, and respondents could withdraw from the study without penalty. Expert identities and individual responses were treated confidentially, and results were reported in aggregated form. The information collected was used solely for research purposes.

RESULTS AND DISCUSSION

This section presents the findings of the Delphi-based evaluation of climate and weather-related risks affecting publicly funded infrastructure projects in Leyte Province. The discussion includes the profile of the expert respondents, the prioritization of identified risks using the Delphi Method and Importance Index, and the effects of the highest-priority risks on project performance. These findings provide localized evidence of the climate-related challenges encountered during infrastructure construction and establish the basis for prioritizing risk management efforts.

Profile of the Delphi Expert Respondents. A total of 18 experts participated in the Delphi process. As presented in Table 2, the respondents represented diverse age groups, educational backgrounds, organizational sectors, professional expertise, and levels of involvement in infrastructure projects. The number of experts was considered adequate for the Delphi process, exceeding the 8–12 experts identified by Hallowell and Gambatese (2010) as a minimum range for Delphi involvement in construction engineering and management research. Thus, the 18 completed responses provided a sufficient expert panel for the present study.

All 18 experts had at least 11 years of professional experience: 50.00% had 11–15 years, 22.22% had 16–20 years, and 27.78% had more than 20 years. Their expertise covered multiple infrastructure sectors and project functions. Because multiple responses were permitted, the results reflect overlapping professional specializations and responsibilities. This multidisciplinary experience provided a relevant basis for evaluating climate- and weather-related risks in Leyte.

Table 2

Profile of Delphi Expert Respondents

Profile Characteristic	Category	Frequency (f)	Percentage (%)
Age Group	31–40 years	10	55.56
	41–50 years	4	22.22
	51–60 years	2	11.11
	61 years and above	2	11.11
Educational Attainment	Bachelor's Degree	11	61.11
	Master's Degree	5	27.78
	Doctorate Degree	2	11.11
Sector/Type of Organization*	Government	8	44.44
	Private Construction Firms	8	44.44
	Consultancy	2	11.11
	Academe	4	22.22
Years of Professional Experience	11–15 years	9	50.00
	16–20 years	4	22.22
	More than 20 years	5	27.78
Primary Areas of Expertise*	Roads and Highways	13	72.22
	Bridges	9	50.00
	Flood Control and Drainage	9	50.00
	Coastal Protection	5	27.78
	Slope Protection and Earthworks	12	66.67
	Public Buildings	12	66.67
	Project Management and Supervision	12	66.67
	Climate and Hazard Assessment	5	27.78
	Academe/Research	2	11.11
	GIS Mapping	2	11.11
	Quality Assurance	1	5.56
	Procurement	2	11.11
Nature of Involvement in Infrastructure Projects*	Planning	11	61.11
	Design	9	50.00
	Construction	13	72.22
	Supervision	15	83.33
	Project Management	11	61.11
	Policy and Regulation	6	33.33
	Research	3	16.67

Note. *Multiple responses were permitted for the categories "Sector/Type of Organization," "Primary Areas of Expertise," and "Nature of Involvement in Infrastructure Projects." Therefore, the total frequencies and percentages for these categories may exceed the total number of respondents (n = 18) and may not sum to 100%. Percentages were calculated using the total number of respondents (n = 18) as the denominator.*

Identification, Assessment, and Prioritization of Climate and Weather-Related Risks. The three Delphi rounds yielded a final inventory of 49 climate- and weather-related risks affecting publicly funded infrastructure projects in Leyte Province. The risks were grouped into seven themes: typhoon-related risks; heavy rainfall and flooding; landslides and soil movement; extreme heat and drought; coastal and sea-level rise hazards; risk management and policy-related gaps; and community and social adaptation. Table 3 presents the Frequency Index (FI), Severity Index (SI), Importance Index (II), and corresponding rankings used to establish the relative priority of each risk.

The final inventory comprised 49 consolidated climate- and weather-related risks, of which 31 were derived from the literature review, and 18 emerged exclusively from the Delphi Round 1 expert responses. The expert-originated risks were coded A6, A7, B6, B7, C5, C6, C7, C8, D5, D6, E5, E6, E7, F7, F8, G4, G5, and G6. Similar or overlapping responses were consolidated into common risk statements, while distinct risk concepts were retained to minimize duplication and preserve relevant risk factors. The resulting inventory underwent quantitative assessment in Delphi Round 2 and consensus assessment in Round 3.

As shown in Table 3, A6 - disruption of project logistics and material delivery during typhoon events ranked first (II = 0.693), followed by A2 - delay or suspension of construction activities due to typhoon events (II = 0.667) and E1 - storm surge impacts on coastal infrastructure (II = 0.604). These results indicate that the panel considered typhoon-related disruptions and coastal hazards to be the most consequential risks to project implementation.

Table 3

Summary of Delphi Rounds 1, 2, and 3 Results: Frequency, Severity, Importance Index, and Priority Ranking of Climate and Weather-Related Risks

Code	Risk Factor	FI	SI	II	Rank	Classification
A	**Typhoon and Strong Wind-Related Risks**					
A1	Damage to temporary facilities and site structures due to strong winds	0.6889	0.6778	0.4669	24	Moderate
A2	Delay or suspension of construction activities due to typhoon events	0.8111	0.8222	0.6669	2	High
A3	Damage to construction materials and ongoing works	0.6778	0.6889	0.4669	24	Moderate
A4	Structural deformation and instability of temporary construction structures	0.5333	0.5556	0.2963	48	Low
A5	Accidents and safety hazards caused by strong winds	0.5778	0.6222	0.3595	45	Low
A6	Disruption of project logistics and material delivery during typhoon events	0.8000	0.8667	0.6933	1	High
A7	Damage to traffic control devices and temporary safety installations	0.6556	0.5889	0.3860	39	Low
B	**Heavy Rainfall and Flooding-Related Risks**					
B1	Site flooding affecting construction operations	0.6778	0.7111	0.4820	21	Moderate
B2	Water damage to construction materials, equipment, and access roads	0.6111	0.6333	0.3870	37	Low
B3	Erosion and soil instability around construction sites	0.6556	0.7222	0.4735	23	Moderate
B4	Sedimentation and drainage obstruction	0.5889	0.6111	0.3599	44	Low
B5	Rework and cost increase due to repeated flooding	0.6111	0.7111	0.4346	29	Moderate
B6	Delays in inspections and project validation due to rainfall	0.7444	0.7556	0.5625	8	Moderate
B7	Floodwater intrusion and overflow of rivers affecting project sites	0.6222	0.7333	0.4563	28	Moderate
C	**Landslides and Soil Movement Risks**					
C1	Slope failure affecting project sites	0.6000	0.7111	0.4267	30	Moderate
C2	Landslides causing access restrictions and project delays	0.7333	0.7778	0.5704	7	Moderate
C3	Sediment deposition clogging drainage systems	0.6333	0.6444	0.4081	33	Moderate
C4	Additional stabilization and rehabilitation measures	0.6444	0.7111	0.4583	27	Moderate
C5	Rockfall hazards affecting infrastructure projects	0.5778	0.6667	0.3852	40	Low
C6	Foundation instability and settlement	0.4333	0.5333	0.2311	49	Low
C7	Embankment instability and movement	0.5667	0.6778	0.3841	42	Low
C8	Failure of temporary soil-retention and excavation support systems	0.5778	0.6556	0.3788	43	Low
D	**Extreme Heat and Drought-Related Risks**					
D1	Reduced labor productivity and work efficiency	0.7333	0.7667	0.5622	11	Moderate
D2	Poor concrete curing and heat-related cracking	0.6778	0.7000	0.4744	22	Moderate
D3	Equipment overheating and pavement deterioration	0.5778	0.6667	0.3852	40	Low
D4	Increased resource consumption during extreme heat	0.6333	0.6444	0.4081	33	Moderate
D5	Worker heat stress and health-related risks	0.7556	0.7333	0.5541	13	Moderate
D6	Moisture loss affecting earthworks and construction quality	0.6222	0.6333	0.3941	36	Low
E	**Coastal and Sea-Level Rise Hazards**					
E1	Storm surge impacts on coastal infrastructure	0.7556	0.8000	0.6044	3	High
E2	Saltwater-induced corrosion of construction materials	0.7111	0.8111	0.5768	6	Moderate
E3	Coastal erosion affecting foundation stability	0.6778	0.7556	0.5121	15	Moderate
E4	Wave action affecting construction operations	0.6778	0.7222	0.4895	19	Moderate
E5	Coastal flooding and tidal inundation	0.6222	0.6778	0.4217	32	Moderate
E6	Damage to temporary coastal facilities	0.6111	0.6556	0.4006	35	Moderate
E7	Seawater contamination of materials	0.6111	0.6333	0.3870	37	Low
F	**Risk Management and Policy-Related Gaps**					
F1	Inadequate climate risk assessment	0.6333	0.6667	0.4222	31	Moderate
F2	Limited awareness and training on climate risks	0.7000	0.7000	0.4900	17	Moderate
F3	Weak coordination among stakeholders	0.6667	0.7000	0.4667	26	Moderate
F4	Poor early warning and monitoring systems	0.7333	0.7667	0.5622	11	Moderate
F5	Limited use of resilient and sustainable materials	0.7444	0.7556	0.5625	8	Moderate
F6	Insufficient funding for adaptation measures	0.8000	0.7444	0.5956	4	Moderate
F7	Delayed climate-responsive decision-making	0.7444	0.7556	0.5625	8	Moderate
F8	Poor documentation and monitoring	0.7778	0.7111	0.5531	14	Moderate
G	**Community and Social Adaptation**					
G1	Low community awareness of climate-related construction hazards	0.7889	0.7444	0.5873	5	Moderate
G2	Transportation and logistics disruption	0.7000	0.7000	0.4900	17	Moderate
G3	Community resistance and lack of cooperation	0.7000	0.6889	0.4822	20	Moderate
G4	Community evacuation affecting project implementation	0.5556	0.5889	0.3272	47	Low
G5	Community displacement and access restrictions	0.5667	0.6222	0.3526	46	Low
G6	Public safety concerns	0.6889	0.7333	0.5052	16	Moderate

Note. *Tied ranks are assigned to risks with identical Importance Index (II) values. Rankings are based on unrounded II values, while reported values are rounded to four decimal places; therefore, apparent ties may have different ranks when their underlying values differ.*

The high ranking of A6 and A2 is consistent with Schuldt et al. (2021), who identified precipitation, high winds, and other adverse weather conditions as major sources of construction delays, affecting task feasibility, productivity, materials, and project schedules. Similarly, Dong et al. (2025) found that weather conditions can significantly influence construction time, cost, and quality. The present findings therefore reinforce previous evidence that weather-related risks affect construction not only through physical damage but also through interruption of activities and disruption of project logistics.

The results also highlight risks beyond direct weather hazards. F6 – insufficient funding for adaptation measures ranked fourth (II = 0.596), while G1 – low community awareness of climate-related construction hazards ranked fifth (II = 0.587). This suggests that experts view institutional capacity and community preparedness as important components of climate-risk management. This is consistent with Pulhin et al. (2022), who emphasized the importance of resources, risk assessment, adaptation, and institutional capacity in strengthening climate responsiveness in the Philippine context.

The Round 3 Delphi results showed varying levels of consensus across the risk classifications, based on the predefined criterion of an interquartile range (IQR) of ≤ 1. High-priority risks generally achieved consensus among the experts. The majority of moderate-priority risks also met the consensus criterion, with only a small proportion failing to achieve consensus, primarily those ranked 30th to 37th, whose Importance Index values were near the lower boundary of the moderate classification. In contrast, most low-priority risks exhibited IQR values greater than 1. This pattern is consistent with the purpose of the Delphi method, which is to assess the extent of agreement among experts through iterative assessment and feedback (Hallowell & Gambatese, 2010; Sourani & Sohail, 2015). Overall, the findings indicate that expert agreement was generally maintained for high- and moderate-priority risks, although greater variability was observed in assessments of risks with relatively lower Importance Index values.

Although G2 and A6 both relate to transportation and logistics disruptions, they differ in scope. A6 specifically concerns disruptions to project logistics and material delivery during typhoon events, whereas G2 addresses broader transportation and logistics constraints affecting communities surrounding project areas. This distinction supports their separate classification in the risk inventory.

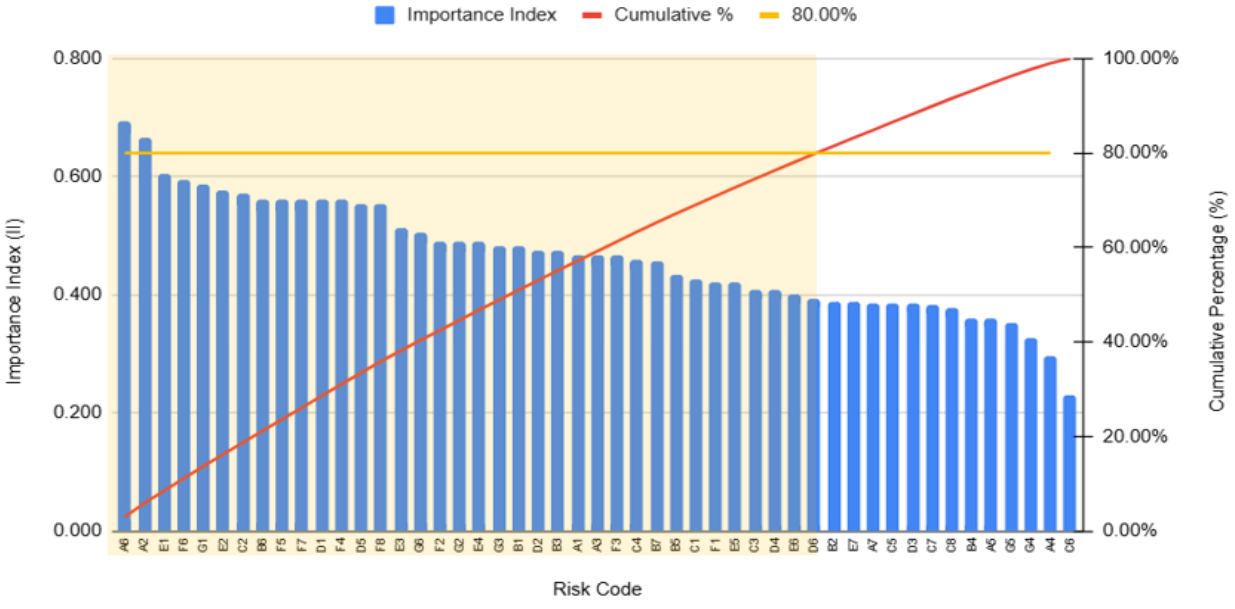


Figure 2
Pareto Analysis of Climate- and Weather-Related Risks Based on Importance Index

Pareto Analysis of Climate and Weather-Related Risks. Pareto analysis was conducted to determine the cumulative contribution of the 49 identified climate- and weather-related risks based on their Importance Index (II). The risks were arranged in descending order of II, and the cumulative percentage was calculated by dividing the cumulative sum of the ranked II values by the total sum of the II values for all 49 risks and multiplying by 100. The 80% threshold was used to identify the number of risks accounting for approximately 80% of the total Importance Index. The results of this analysis are presented in Figure 2.

The Pareto distribution indicates that climate and weather-related risks in infrastructure projects in Leyte are not concentrated in only a few individual risks. Instead, a relatively broad group of risks contributes substantially to the overall risk importance. This finding is consistent with Schuldt et al. (2021), who reported that adverse weather can affect construction through multiple pathways, including work activities, productivity, materials, labor, equipment, and project schedules. Similarly, Dong et al. (2025) found that weather conditions can influence several dimensions of construction performance, particularly project time, cost, and quality. The present findings extend these studies by demonstrating that the perceived climate-related risk exposure in the Leyte infrastructure context is distributed across numerous risk factors rather than being limited to a small number of dominant hazards. The fact that 37 risks are required to reach the 80% threshold also has practical implications for risk management.

While the highest-ranked risks in Table 3 should receive greater attention during planning and implementation, the lower-ranked risks should not be completely excluded from monitoring and contingency planning. This is particularly important because climate-related risks can interact with one another.

For example, a typhoon may simultaneously disrupt logistics, suspend construction activities, restrict access, and create community-related concerns. Pulhin et al. (2022) similarly emphasized that climate responsiveness requires consideration of interconnected risks, adaptation measures, institutional capacity, and integrated planning.

The Pareto results support a tiered approach: prioritize higher-ranked risks for mitigation and resource allocation while retaining the remaining risks in monitoring and contingency plans.

Comparative Assessment. The Kruskal–Wallis test was conducted to determine whether the experts' assessments differed according to their demographic and professional characteristics in terms of the frequency of occurrence and level of impact of the identified climate- and weather-related risks. The results are presented in Tables 4 and 5, respectively.

As shown in Table 4, no statistically significant differences were found in the perceived frequency of the risks, with all p-values exceeding 0.05. This indicates that the experts generally shared similar views regarding how frequently climate- and weather-related risks occur, regardless of their demographic and professional characteristics. This consistency is relevant to construction projects because, according to Schuldt et al. (2021), adverse weather conditions such as precipitation, extreme temperatures, and high winds can affect construction activities, productivity, and project schedules across different project contexts.

Most comparisons of perceived impact were likewise not statistically significant (Table 5). However, a significant difference was found for Landslides and Soil Movement Risks according to Sector/Type of Organization ($H = 9.649$, $df = 3$, $p = 0.022$). This suggests that professionals from different sectors may perceive the consequences of landslide-related risks differently, possibly because of differences in responsibilities and exposure to project conditions. According to Cordero et al. (2025), landslide risk in the Philippines is highly site-specific and is better understood by considering local conditions, exposure, vulnerability, and the perspectives of different stakeholders.

This finding supports the importance of incorporating cross-sector perspectives in assessing landslide risks. It also complements the broader climate-risk perspective of Pulhin et al. (2022), who emphasized integrated planning, interconnected risks, and multi-stakeholder collaboration in strengthening climate responsiveness in the Philippines.

The generally non-significant results indicate a substantial level of agreement among the experts, while the significant difference for landslide risks highlights an area where sector-specific experience and responsibilities may influence risk perception.

The degrees of freedom (df) reported in Tables 4 and 5 vary according to the number of categories under each respondent characteristic. Academic background, number of published research outputs, and total years of professional experience in infrastructure projects each have 2 degrees of freedom, corresponding to three groups. Age group and sector/type of organization have 3 degrees of freedom, while primary area of expertise and nature and involvement in projects have 8 and 6 degrees of freedom, respectively. These degrees of freedom are consistent with the number of groups compared in the Kruskal–Wallis tests and apply to the frequency and

Table 4

Comparative Assessment of the Frequency of Occurrence of Climate and Weather-Related Risks According to Respondents' Demographic and Professional Characteristics

Variable	Typhoon and Strong Wind		Heavy Rainfall and Flooding		Landslides and Soil Movement		Extreme Heat and Drought		Coastal and Sea-Level Rise		Risk Management and Policy-Related Gaps		Community and Social Adaptation	
	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value
Age Group	7.123	0.068	1.225	0.747	3.932	0.269	4.600	0.204	3.953	0.267	0.526	0.913	3.162	0.367
Academic Background	0.553	0.759	2.979	0.226	0.581	0.748	1.505	0.471	0.832	0.660	1.511	0.470	0.346	0.841
Number of Published Research Outputs	0.096	0.757	1.025	0.311	1.326	0.250	0.133	0.715	0.015	0.903	2.683	0.102	0.090	0.764
Sector/Type of Organization	5.620	0.132	1.715	0.634	7.047	0.070	2.460	0.483	7.180	0.066	2.603	0.457	5.279	0.153
Years of Professional Experience	3.435	0.180	0.153	0.926	1.106	0.575	2.329	0.312	1.611	0.447	0.605	0.739	3.052	0.217
Primary Area of Expertise	3.266	0.917	10.282	0.246	12.208	0.142	8.463	0.390	5.315	0.724	11.527	0.174	6.876	0.550
Nature and Involvement in Projects	8.298	0.217	5.542	0.477	10.088	0.121	10.789	0.095	9.641	0.141	10.439	0.107	9.759	0.135

Note. *χ^2 = Kruskal–Wallis test statistic. Statistical significance was set at $\alpha = 0.05$. No statistically significant differences were observed across all demographic and professional characteristics (all $p > 0.05$).*

Table 5

Comparative Assessment of the Level of Impact of Climate- and Weather-Related Risks According to Respondents' Demographic and Professional Characteristics

Variable	Typhoon and Strong Wind		Heavy Rainfall and Flooding		Landslides and Soil Movement		Extreme Heat and Drought		Coastal and Sea-Level Rise		Risk Management and Policy-Related Gaps		Community and Social Adaptation	
	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value
Age Group	3.155	0.368	1.026	0.795	4.150	0.246	3.569	0.312	0.610	0.894	0.132	0.988	1.501	0.682
Academic Background	0.100	0.951	4.697	0.096	0.111	0.946	0.972	0.615	2.348	0.309	1.737	0.420	0.560	0.756
Number of Published Research Outputs	0.137	0.711	2.390	0.122	0.092	0.762	0.941	0.332	0.563	0.453	2.682	0.101	0.818	0.366
Sector/Type of Organization	3.545	0.315	6.600	0.086	9.649	0.022	2.150	0.542	7.184	0.066	1.667	0.644	0.429	0.699
Years of Professional Experience	5.836	0.054	1.287	0.526	0.923	0.630	3.438	0.179	0.728	0.695	2.730	0.255	2.774	0.250
Primary Area of Expertise	8.157	0.418	6.932	0.544	6.244	0.620	11.045	0.199	6.624	0.578	11.214	0.190	11.315	0.183
Nature and Involvement in Projects	5.652	0.463	7.045	0.317	9.052	0.171	10.735	0.097	8.477	0.205	10.653	0.100	8.599	0.200

Note. *χ^2 = Kruskal–Wallis test statistic. Statistical significance was set at $\alpha = 0.05$. A statistically significant difference was observed for Landslides and Soil Movement Risks according to Sector/Type of Organization ($\chi^2 = 9.649$, $p = 0.022$). All other comparisons were not statistically significant ($p > 0.05$).*

impact assessments presented in Tables 4 and 5.

Effects on Project Time, Cost, Quality, and Safety. The climate- and weather-related risks identified through the Delphi process were further assessed in terms of their perceived effects on project time, cost, construction quality, and worker safety (TCQS). This assessment provided a more detailed understanding of how the prioritized risks may affect project performance beyond their overall Importance Index. The results are presented according to risk priority, with Figure 3 showing the high-priority risks and Figures 4a–4c presenting the moderate-priority risks.

As shown in Figure 3, the three high-priority risks exhibited different patterns of impact across the TCQS dimensions. A6-disruption of project logistics and material delivery during typhoon events recorded a mean Level of Impact of 4.33, with the highest effects on cost and construction quality, both at 4.89, followed by safety at 4.28 and time at 3.44. A2—delay or suspension of construction activities due to typhoon events showed particularly high effects on project time and worker safety, both with mean scores of 4.78. Meanwhile, E1-storm surge impacts on coastal infrastructure-exhibited relatively balanced effects across the four dimensions, with scores close to 4.00. These findings suggest that high-priority climate-related risks can affect different aspects of project performance through distinct pathways.

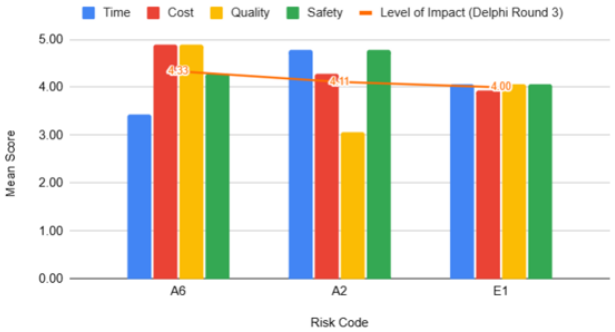


Figure 3
TCQS Scores and Mean Level of Impact of High-Priority Climate and Weather-Related Risks

These results are consistent with Schuldt et al. (2021), who discussed how adverse weather conditions can disrupt construction activities, productivity, labor, equipment, and material supply. Similarly, Dong et al. (2025) highlighted the influence of weather conditions on construction time, cost, and quality. The present findings illustrate these interconnected effects, particularly for typhoon-related logistics disruptions and work stoppages.

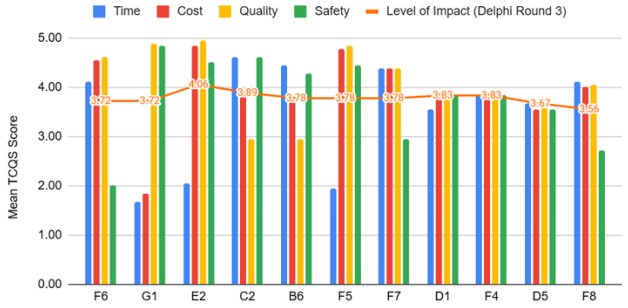


Figure 4a
TCQS Scores and Mean Level of Impact of Moderate-Priority Climate and Weather-Related Risks (Ranks 4–14)

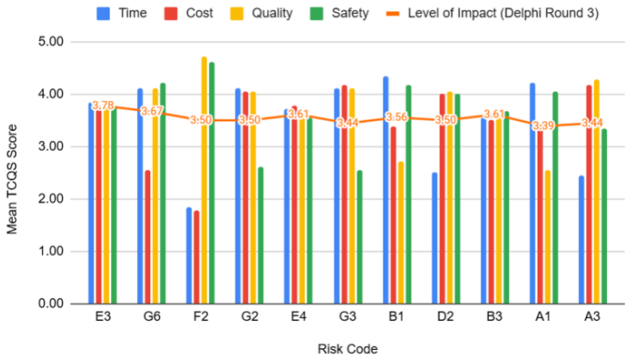


Figure 4b
TCQS Scores and Mean Level of Impact of Moderate-Priority Climate and Weather-Related Risks (Ranks 15-25)

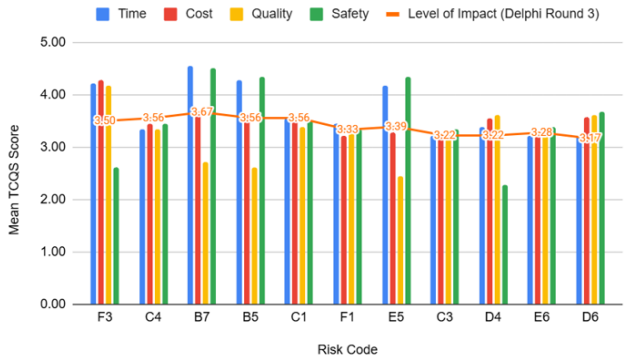


Figure 4c
TCQS Scores and Mean Level of Impact of Moderate-Priority Climate and Weather-Related Risks (Ranks 26-36)

Figures 4a–4c present the TCQS scores and mean Level of Impact for the moderate-priority risks. Although these risks have lower Importance Index values than the high-priority risks, several exhibit substantial effects on specific project performance dimensions. In Figure 4a, E2-saltwater-induced corrosion of construction materials-recorded high mean scores for cost (4.83) and quality (4.94), with an overall Level of Impact of 4.06. G1 also showed contrasting results, with comparatively low time and cost scores but high quality and safety scores. These patterns indicate that the overall priority of a risk does not necessarily reflect the magnitude of its effect on every TCQS dimension.

Figure 4b shows that E3 and G6 recorded mean Levels of Impact of 3.78 and 3.76, respectively. Other risks in this group also exhibited differences across the TCQS dimensions. For example, F2 had high quality (4.72) and safety (4.61) scores, whereas A3 showed relatively high cost (4.17) and quality (4.28) scores. Figure 4c presents the remaining moderate-priority risks, with mean Levels of Impact ranging from 3.17 to 3.67. Within this group, B7 recorded a relatively high time score (4.56) and safety score (4.50), while E5 showed high time (4.17) and safety (4.33) scores but a lower quality score (2.44). These variations demonstrate that moderate-priority risks can have different implications for individual aspects of construction project performance.

The findings align with Schuldt et al. (2021) and Dong et al. (2025), who discussed the effects of adverse weather on construction activities and project performance. They also support Pulhin et al. (2022) on the importance of integrated planning and coordination for climate responsiveness.

For a consolidated numerical comparison, Table 6 presents the mean TCQS scores and corresponding Level of Impact for the high- and moderate-priority risks. The table complements Figures 3 and 4a–4c by providing the numerical results underlying the graphical comparisons and facilitating comparison across the four project performance dimensions.

Overall, Figures 3 and 4a–4c and Table 6 demonstrate the value of examining climate- and weather-related risks through both their overall priority and their specific TCQS effects. High-priority risks warrant focused mitigation because of their substantial overall significance, while moderate-priority risks should not be disregarded when they exhibit high effects on particular performance dimensions. Integrating risk rankings with TCQS assessments can support more targeted planning, resource allocation, quality management, and safety measures for infrastructure projects in Leyte.

Table 6

Mean TCQS Scores and Level of Impact of High- and Moderate-Priority Climate- and Weather-Related Risks

Risk Code	Time	Cost	Quality	Safety	Level of Impact
High-priority risks					
A6	3.44	4.89	4.89	4.28	4.33
A2	4.78	4.28	3.06	4.78	4.11
E1	4.06	3.94	4.06	4.06	4.00
Moderate-priority risks					
F6	4.11	4.56	4.61	2.00	3.72
G1	1.67	1.83	4.89	4.83	3.72
E2	2.06	4.83	4.94	4.50	4.06
C2	4.61	3.89	2.94	4.61	3.89
B6	4.44	3.78	2.94	4.28	3.78
F5	1.94	4.78	4.83	4.44	3.78
F7	4.39	4.39	4.39	2.94	3.78
D1	3.56	3.89	3.83	3.83	3.83
F4	3.83	3.89	3.78	3.83	3.83
D5	3.67	3.56	3.78	3.56	3.67
F8	4.11	4.00	4.06	2.72	3.56
E3	3.83	3.78	3.83	3.78	3.78
G6	4.11	2.56	4.11	4.22	3.67
F2	1.83	1.78	4.72	4.61	3.50
G2	4.11	4.06	4.06	2.61	3.50
E4	3.72	3.78	3.56	3.56	3.61
G3	4.11	4.17	4.11	2.56	3.44
B1	4.33	3.39	2.72	4.17	3.56
D2	2.50	4.00	4.06	4.00	3.50
B3	3.56	3.50	3.61	3.67	3.61
A1	4.22	3.39	2.56	4.06	3.39
A3	2.44	4.17	4.28	3.33	3.44
F3	4.22	4.28	4.17	2.61	3.50
C4	3.33	3.44	3.33	3.44	3.56
B7	4.56	3.67	2.72	4.50	3.67
B5	4.28	3.61	2.61	4.33	3.56
C1	3.56	3.50	3.39	3.50	3.56
F1	3.44	3.22	3.28	3.33	3.33
E5	4.17	3.28	2.44	4.33	3.39
C3	3.22	3.22	3.17	3.33	3.22
D4	3.39	3.56	3.61	2.28	3.22
E6	3.22	3.22	3.22	3.39	3.28
D6	3.22	3.56	3.61	3.67	3.17

Note. *TCQS scores are mean expert ratings. The Level of Impact values are reported from Delphi Round 3. Risk ranks follow the Importance Index ranking in Table 3; tied ranks are retained where applicable. Values are rounded to two decimal places.*

Conclusion. This study evaluated climate- and weather-related risks affecting publicly funded infrastructure projects in Leyte Province using a three-round Delphi Method. The process yielded a final inventory of 49 risks grouped into seven thematic categories, reflecting the environmental, operational, institutional, and community-related challenges encountered in infrastructure project implementation. By integrating literature-derived risks with expert knowledge, the study established a localized risk inventory reflecting both existing research and the specific context of infrastructure construction in Leyte.

The findings identified typhoon-related risks among the most critical concerns, particularly the disruption of project logistics and material delivery during typhoon events, delay or suspension of construction activities, and storm surge impacts on coastal infrastructure. These risks can affect project implementation through disruptions to transportation, construction schedules, material supply, and site accessibility. The Pareto analysis further showed that a substantial proportion of the identified risks contributed to the overall risk profile, highlighting the need to consider risks beyond those with the highest rankings.

The TCQS assessment revealed that the identified risks were perceived by experts to have varying effects on project time, cost, construction quality, and worker safety. High-priority risks demonstrated substantial effects on specific project performance dimensions, while several moderate-priority risks also exhibited notable impacts. These findings emphasize the importance of considering the specific performance consequences of climate- and weather-related risks, rather than relying solely on their overall rankings, when developing construction management and adaptation measures.

Limitations of the Study. This study has several limitations that should be considered when interpreting its findings. First, although the Delphi panel consisted of 18 experienced infrastructure professionals, the relatively small panel may limit the transferability of the findings to other contexts. Second, the study focused exclusively on public infrastructure projects in Leyte Province, Philippines; therefore, the identified risks and their prioritization may differ in other provinces with different hazard exposures, infrastructure characteristics, and institutional settings. Third, the assessment relied on expert judgments and perceptions rather than systematic validation against actual project records, such as documented construction delays, cost overruns, quality deficiencies, and safety incidents. Consequently, the Importance Index rankings and TCQS assessments represent expert-based evaluations rather than empirically established measures of project performance. Finally, the detailed assessment of effects on project time, cost, quality, and safety was limited to selected priority risks. The TCQS findings therefore do not represent the effects of all 49 identified risks on the four project-performance dimensions. These limitations should be considered when applying the findings to other infrastructure projects or using them to guide risk-management decisions.

Directions for Future Research. Future studies may validate the prioritized risks using actual project records, including documented delays, cost variations, quality issues, and safety incidents. Similar Delphi studies may also be conducted in other provinces in Eastern Visayas and other climate-vulnerable regions of the Philippines to determine whether the identified risk priorities are consistent across locations. Further research may evaluate the effectiveness of specific climate adaptation and construction management measures and develop a climate- and weather-related risk register or assessment tool that can be used by government agencies, contractors, and project managers in infrastructure planning and implementation. The findings provide a localized basis for prioritizing climate- and weather-related risks and informing mitigation planning for public infrastructure projects in Leyte.

DISCLOSURES

Author contributions. Ben Daniel N. Gamutan: Conceptualization, methodology, data collection, formal analysis, investigation, data curation, visualization, writing-original draft, and writing-review and editing | Marvin O. Mallari: Conceptualization, supervision, validation, methodology review, and writing-review and editing. Both authors reviewed and approved the final version of the manuscript and agreed to be accountable for the work.

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Ethics approval statement. This study received ethical clearance from the University Research Ethics Committee of the Polytechnic University of the Philippines (PUP-UREC) under OUSREC Code 0226-0098. The study was granted an exempted review and was approved on March 6, 2026, with the ethical clearance valid until March 6, 2027. The research was conducted in accordance with the approved research protocol and applicable ethical requirements.

Data availability statement. The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to applicable ethical and confidentiality requirements.

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