TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

Thesis No.: PUL080MSCoM022

Probabilistic Assessment of Safety Risks in Irrigation Construction Projects in Nepal

by

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080MSCoM022

A THESIS
SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER IN CONSTRUCTION MANAGEMENT

DEPARTMENT OF CIVIL ENGINEERING
LALITPUR, NEPAL

April 2026

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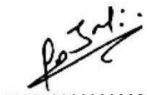

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ACKNOWLEDGEMENT

First and foremost, sincere gratitude is extended to the thesis supervisor, Er. Subash Kumar Bhattarai, for his invaluable guidance, insightful feedback, and continuous encouragement throughout the study. His expertise and constructive suggestions have been instrumental in shaping this thesis.

Sincere appreciation is also extended to the Program Coordinator, Asst. Professor Mahendra Raj Dhital, for his continuous support and for providing the opportunity to undertake this research as part of the Master of Science in Construction Management program.

Gratitude is further expressed to all experts and respondents who generously shared their knowledge and insights, which significantly enriched the quality of this study.

Special acknowledgment is given to fellow engineers, friends, and colleagues, Mrs. Neha Kumari Singh, Miss Sabina Shrestha, and Mr. Avishek Kumar Rouniyar, for their valuable support and assistance during data collection. Their cooperation and contribution greatly facilitated the successful completion of this research.

Finally, heartfelt thanks are extended to family and friends for their unwavering support, patience, and encouragement throughout this journey. Their constant motivation has been a source of strength.

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ABSTRACT

Construction safety in irrigation projects remains critically underdeveloped in Nepal despite the sector's substantial contribution to national agricultural development. The convergence of excavation, water-related hazards, slope instability, and remote site operations makes safety management in irrigation construction uniquely challenging.

This study aimed to: (i) identify, validate, and structure key safety factors; (ii) prioritize them based on relative significance; and (iii) assess overall safety performance under uncertainty. An integrated five-stage framework was developed. An initial pool of 32 safety factors from the literature was subjected to expert validation using Content Validity Index (CVI). Principal Component Analysis (PCA) of survey data from 68 experienced professionals identified underlying safety dimensions. Analytic Hierarchy Process (AHP) derived global priority weights. A composite Safety Index was evaluated probabilistically using Monte Carlo Simulation over 10,000 iterations.

Expert validation retained 28 factors (Scale-Level CVI = 0.954). PCA identified five dimensions explaining 70.74% of total variance: Site Operations (21.04%); Management Systems (18.20%); Inspection & Culture (12.94%); Training & Behavior (11.24%); and Housekeeping (7.33%). AHP identified insufficient safety budget (w = 0.1050), lack of clear instructions (w = 0.0793), and insufficient training (w = 0.0644) as top risks. The deterministic Safety Index was 0.512. Monte Carlo Simulation produced a mean Safety Index of 0.512 (SD = 0.045; 90% CI: [0.438, 0.587]), with 99.33% of outcomes in the Moderate category, 0.67% in Unsafe, and no simulation reaching Safe.

Irrigation construction projects in Nepal operate under persistent moderate safety risk, driven primarily by organizational and managerial deficiencies. No Safe outcome is achievable under current conditions without fundamental, multi-dimensional improvement. The integrated framework offers a transferable methodology for uncertainty-aware safety assessment in data-limited infrastructure contexts.

Keywords: *Construction Safety; Probabilistic Risk Assessment; Principal Component Analysis; Analytic Hierarchy Process; Monte Carlo Simulation; Safety Index; Irrigation Construction; Nepal*

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LIST OF ABBREVIATIONS

AHP – Analytic Hierarchy Process

CVI – Content Validity Index

PCA – Principal Component Analysis

MCS – Monte Carlo Simulation

SD – Standard Deviation

CI – Confidence Interval

ILO – International Labour Organization

OSH – Occupational Safety and Health

DWRI – Department of Water Resources and Irrigation

GDP – Gross Domestic Product

KMO – Kaiser-Meyer-Olkin (Measure of Sampling Adequacy)

CR – Consistency Ratio

SEM – Structural Equation Modeling

PPE – Personal Protective Equipment

RQ – Research Question

Eq. – Equation

n – Sample Size / Number of Observations

Z – Z-score (Standard Normal Value)

p – Population Proportion

e – Margin of Error

CHAPTER 1: INTRODUCTION

1.1 Background

The construction industry is universally recognized as one of the most hazardous industrial sectors, characterized by a dynamic working environment, a high dependence on manual labor, and continuously changing site conditions. According to the International Labour Organization (ILO, 2023), construction and agriculture together account for approximately 63% of all fatal occupational injuries globally, despite representing a far smaller fraction of the total workforce. Beyond fatalities, accidents disrupt project schedules, elevate costs, and reduce productivity. Hinze et al. (2013) demonstrated that projects with robust safety management systems not only achieved lower accident rates but also outperformed in schedule adherence and cost control.

Construction safety challenges are considerably more severe in developing and transitional economies. Durdyev et al. (2017) found that weak regulatory frameworks, inadequate enforcement capacity, and constrained financial resources collectively undermine safety performance across developing nations. In the South Asian context, Bajracharya et al. (2023) highlighted that occupational health and safety challenges persist largely due to gaps in policy implementation, fragmented enforcement mechanisms, and the absence of systematic safety monitoring in infrastructure projects.

Nepal presents a particularly instructive case. As a landlocked mountainous country, Nepal faces construction safety challenges that are both institutional and environmental in nature. The construction sector has expanded significantly, driven by post-earthquake reconstruction, hydropower development, rural road expansion, and large-scale irrigation infrastructure investment. Yet the institutional framework for occupational safety and health remains nascent. The ILO National Occupational Safety and Health Profile for Nepal (2022) noted that Nepal had ratified only 11 of 190 ILO Conventions as of 2021. Tripathi and Shrestha (2018) similarly observed that infrastructure projects in Nepal are exposed to heightened

accident risks stemming from technical complexities and a systemic lack of structured safety management.

Among the various infrastructure sub-sectors, irrigation construction projects occupy a position of particular significance in Nepal. The agricultural sector contributes approximately one-quarter of Nepal's gross domestic product and provides livelihoods for the majority of the rural population. Irrigation construction projects, however, present a distinct and more complex safety profile than conventional building projects. They typically involve extensive excavation and earth-moving operations, canal construction and lining, headwork and diversion structures, slope stabilization in unstable hillside terrain, pipe laying under variable hydrological conditions, and sustained work in water-exposed and waterlogged environments. The convergence of these hazards, trench collapse risks, drowning, soil destabilization, equipment malfunction in wet conditions, landslides, and rockfalls, in a single project environment, makes safety management in irrigation construction substantially more demanding than in standard urban construction. Despite this elevated risk profile, irrigation construction projects have received comparatively little attention in the academic safety literature, and systematic frameworks for evaluating safety performance in this sub-sector remain underdeveloped.

1.2 Problem Statement

Construction safety in Nepal remains a critical concern, with the sector continuing to record elevated accident rates driven by inadequate safety management practices, an informal workforce, weak institutional enforcement, and complex environmental conditions (Bajracharya et al., 2023; Tripathi & Shrestha, 2018). These challenges are particularly pronounced in infrastructure sub-sectors such as irrigation, where the combination of high-risk activities and remote, environmentally exposed operating conditions creates a safety profile that is qualitatively different from general building construction.

Despite the elevated hazard exposure in irrigation construction, the volume of safety research specifically addressing this sub-sector is strikingly limited. Tamara et al. (2020) identified potentially hazardous risk sources across multiple work components of irrigation channel construction, including earthworks, concrete canal lining, and hydraulic structure

installation, concluding that a structured safety plan was essential for reducing accident risk on such sites. A study evaluating occupational health, safety, and environment implementation in the Rehabilitation Project of the Wawotobi Irrigation Area found that safety compliance was inconsistent and the implementation of safety management provisions did not meet required standards (Baso & Yunus, 2024). More broadly, Mishra and Aithal (2021) documented that irrigation tunnel construction in Nepal involves significant occupational hazards, including rockfall, landslide risk, toxic gas exposure, and noise, and emphasized that safety remains a critical and under-managed concern across Nepal's water resource infrastructure sector. Notwithstanding these contributions, dedicated quantitative safety assessment frameworks specifically designed for irrigation construction in the context of Nepal remain virtually absent from the literature.

The safety assessment approaches currently applied in the Nepalese construction industry are largely informal, relying on experience-based judgment and checklist-type evaluations rather than on structured, evidence-based systems. These methods lack the analytical depth required to identify the relative importance of different safety factors, to account for their interactions, or to reflect the inherent uncertainty of the project environment. This reliance on informal methods limits the ability to make defensible, data-driven decisions about where to direct safety investments and management attention (Pinto et al., 2011).

Furthermore, the academic literature has not yet produced an integrated methodological framework that combines factor identification, content-validity-based expert validation, statistical factor structuring, multi-criteria prioritization, composite safety index development, and probabilistic simulation within a single coherent approach applicable to irrigation construction projects. There is also a notable absence of studies that quantify the overall safety performance level of irrigation construction projects in Nepal under conditions of uncertainty, a gap that severely limits the ability of project managers to benchmark safety conditions or evaluate the effectiveness of safety improvement measures. The absence of such a framework has direct practical consequences: without a validated and structured understanding of which safety factors are most influential, project managers lack a reliable basis for prioritizing safety interventions, allocating safety budgets, or communicating safety performance to project owners and regulatory authorities. Addressing this problem is, therefore, not merely an

academic exercise but a practical necessity for improving worker safety outcomes in a sector with direct consequences for national development goals.

1.3 Research Questions

The study is guided by the following research questions:

RQ1: What are the most critical factors influencing safety in irrigation projects in Nepal, and how can they be structured?

RQ2: Which factors are most critical for safety performance?

RQ3: What is the overall safety level of irrigation construction projects in Nepal when uncertainty is considered?

1.4 Research Objectives

The general objective of this study is to probabilistically assess safety performance in irrigation construction projects in Nepal using an integrated analytical framework. And, the specific objectives are as follows:

i. To systematically identify, validate, and structure the key safety factors influencing irrigation construction projects.

ii. To evaluate and prioritize the identified safety factors based on their relative significance.

iii. To assess the overall safety level of irrigation construction projects under conditions of uncertainty.

1.5 Significance of the Study

This study is justified by both practical and academic grounds. In practice, irrigation infrastructure is central to Nepal's agricultural economy, with significant investment planned under the Nepal Irrigation Policy and the Agricultural Development Strategy. Yet the construction phase, the period of greatest safety risk, consistently lacks structured safety management. Project managers, engineers, and contractors currently have no validated,

context-appropriate framework to guide safety planning, and this study directly addresses that gap.

A probabilistic approach is warranted because construction safety outcomes are inherently uncertain, shaped by varying project conditions, workforce characteristics, and environmental factors. By incorporating Monte Carlo Simulation, the study goes beyond single-point estimates to capture the range and likelihood of different safety outcomes, offering more realistic and actionable insights for decision-makers.

Academically, the study contributes a novel methodological integration, combining CVI-based expert validation, PCA-based factor structuring, AHP-based prioritization, and Monte Carlo Simulation, applied specifically to irrigation construction safety in a developing-country context. While each method appears individually in the literature, its systematic combination within a sector-specific framework is a meaningful contribution. The findings also add to the comparative evidence base on how safety determinants, human, organizational, managerial, technical, and site-related, vary across project types and geographies.

Finally, the framework is transferable. Though grounded in Nepal's irrigation sector, it is adaptable to other infrastructure sub-sectors such as rural roads, small-scale hydropower, or water supply projects, both within Nepal and in comparable developing-country settings, providing a foundation for broader methodological innovation across South Asia.

1.6 Scope and Limitations

1.6.1 Scope of the Study

This study focuses on assessing safety performance in irrigation construction projects in Nepal. It considers the full range of activities commonly involved in such projects, including excavation and trenching, canal construction and lining, headwork and diversion structure construction, slope stabilization, pipe laying, and operations in water-exposed or hydrologically unstable ground conditions.

The safety factors examined in this study were initially identified through a comprehensive review of peer-reviewed literature spanning multiple decades and geographic contexts. These factors were then subjected to expert validation to ensure their contextual

relevance to the Nepalese irrigation construction setting. A structured questionnaire survey was conducted among experienced construction professionals, including project managers, site engineers, and contractors actively involved in irrigation project execution in Nepal. The quantitative data collected through this survey formed the basis for the statistical analysis, prioritization, and probabilistic modeling carried out in the study.

The scope of the Safety Index developed in this study encompasses all validated safety factors, organized into the principal components identified through PCA. The probabilistic assessment is conducted using Monte Carlo Simulation with triangular distributions parameterized by the range of survey responses, enabling the generation of a distribution of Safety Index values that reflects the inherent variability of safety conditions across different project scenarios.

The findings and framework developed in this study are intended to support safety decision-making by project managers, site engineers, contractors, and policy-makers involved in irrigation construction in Nepal. The framework may also serve as a reference model for future safety assessments in comparable infrastructure sub-sectors.

1.6.2 Limitations of the Study

While this study makes several original contributions to the understanding and assessment of safety performance in irrigation construction, a number of limitations should be acknowledged. First, the geographic scope of the study is limited to irrigation construction projects in Nepal. The specific regulatory environment, workforce characteristics, environmental conditions, and institutional context of Nepal shape both the selection of safety factors and the interpretation of results. Accordingly, direct generalization of findings to construction sectors or geographic contexts with substantially different characteristics should be undertaken with caution.

Second, the identification of safety factors is based primarily on a review of published academic literature, supplemented by expert validation. While this approach is standard in construction safety research and provides a rigorous basis for factor selection, it cannot guarantee the exhaustive identification of all relevant factors in every possible project scenario.

Some factors that are contextually important but infrequently reported in the literature may not have been captured in the initial factor pool.

Third, the data collection methodology relies on expert judgment and Likert-scale survey responses from construction professionals. Such self-reported data are subject to response bias, including social desirability bias (the tendency of respondents to overstate compliance with safety norms) and recall bias in the assessment of factor occurrence frequencies. Efforts were made to mitigate these biases through careful questionnaire design and by selecting respondents with direct and recent experience in irrigation project execution, but some degree of bias cannot be eliminated.

These limitations do not diminish the substantive contributions of the study but rather indicate directions in which future research can productively build upon the framework established here.

CHAPTER 2: LITERATURE REVIEW

2.1 Construction Safety and Its Determinants

Construction safety is a fundamental concern in project management, encompassing the comprehensive set of policies, practices, and management systems directed at preventing accidents, minimizing occupational injuries, and protecting the health and welfare of all persons on and around construction sites. The discipline has evolved considerably over the past several decades, transitioning from a reactive focus on post-accident investigation and compensation toward a more proactive orientation centered on hazard identification, risk assessment, and the systematic management of safety determinants before adverse events occur. This evolution reflects a growing recognition that accidents are not random or inevitable events but rather the predictable outcomes of identifiable and controllable conditions.

The foundational insight underpinning contemporary construction safety research is that accidents are rarely, if ever, attributable to a single cause. Sawacha et al. (1999) were among the earliest researchers to demonstrate empirically that construction accidents result from the compound effect of multiple interacting factors, including site conditions, management practices, worker behavior, and environmental circumstances. Their work established that no single factor operates in isolation, and that effective safety management requires an understanding of how these dimensions interact to create or mitigate accident risk. This multidimensional view of accident causation has since become a cornerstone of the field and continues to inform both research design and practical safety management frameworks.

Human-related factors constitute one of the most extensively studied categories of construction safety determinants. These encompass individual worker attributes and behavioral patterns that elevate or reduce the probability of accidents and near-miss events. Unsafe worker behavior, including failure to follow established safety procedures, disregard for established exclusion zones, and non-compliance with personal protective equipment requirements, has been consistently identified as a proximate cause in a majority of recorded construction accidents. Toole (2002) emphasized that the clarity with which safety roles and responsibilities are defined and communicated significantly influences the frequency of unsafe worker actions,

noting that ambiguity in responsibility allocation allows unsafe behavior to persist unaddressed across multiple levels of the project organization.

The importance of safety training as a human factor determinant cannot be overstated. Inadequate training leaves workers unable to recognize hazards, assess risks, or execute protective measures effectively, even when the appropriate protective equipment and infrastructure are physically available. Durdyev et al. (2017) found that insufficient safety training was among the most frequently cited contributors to poor safety performance in construction projects in developing countries, where formal training systems for construction workers are often absent or poorly implemented. Workers in such contexts frequently acquire safety knowledge through informal apprenticeship or by observing experienced colleagues, methods that perpetuate existing unsafe practices rather than instilling evidence-based safety behaviors. This finding is corroborated by Alkilani et al. (2013), who noted that reliance on unskilled and informally trained labor in developing country construction projects is closely associated with elevated accident rates.

Organizational and managerial safety determinants operate at a higher systemic level, shaping the conditions under which individual workers make safety-relevant decisions. Management commitment to safety, manifested through resource allocation for safety programs, active participation of senior management in safety activities, and the consistent enforcement of safety rules, is widely recognized as one of the most influential organizational factors shaping safety culture and performance. Rivera et al. (2021) found that organizations demonstrating a genuine and visible commitment to safety consistently achieved significantly lower accident rates than those where safety was treated as a compliance exercise rather than a strategic priority. The mechanism through which management commitment exerts its influence is largely motivational and cultural: when workers observe that their supervisors and managers take safety seriously, they are more likely to internalize safety norms and exhibit safety-compliant behavior even in the absence of direct supervision.

Safety culture, the shared values, beliefs, and behavioral norms within an organization regarding safety, represents a higher-order determinant that encompasses and moderates the effect of many individual organizational factors. A strong safety culture is characterized by open communication about hazards and near-misses, mutual accountability for safety

practices, proactive identification of risks, and a shared belief that safety takes precedence over production pressure. Conversely, a weak safety culture is marked by under-reporting of incidents, tolerance of unsafe shortcuts, and a general perception that safety regulations are obstacles to efficiency rather than essential protections. Rechenthin (2004) argued persuasively that organizations that cultivate strong safety cultures gain a strategic competitive advantage, as the cost savings from reduced accidents, lower insurance premiums, improved worker retention, and enhanced project reputation more than offset the investments required to build and maintain effective safety programs.

Technical and site-related factors represent a third major category of construction safety determinants. These include the condition and maintenance status of construction equipment, the adequacy of protective systems for excavations and scaffolding, the layout and housekeeping of construction sites, and the management of material handling operations. Improper equipment operation, often resulting from insufficient operator training, fatigue, or unclear supervision, is associated with a significant proportion of struck-by and caught-in-between incidents on construction sites. Inadequate equipment maintenance introduces additional mechanical failure risks, while unsafe site layout creates conditions in which workers, vehicles, and falling objects interact in dangerous proximity. Ng et al. (2005) developed an evaluation framework for contractor safety performance that gave significant weight to technical and site management factors, recognizing that these elements are often more directly observable and measurable than human behavioral factors, making them particularly amenable to systematic assessment.

Environmental factors, including weather conditions, terrain characteristics, and proximity to natural hazards, introduce additional complexity into the safety management equation. Projects conducted in exposed outdoor environments are subject to temperature extremes, precipitation, high winds, and reduced visibility, all of which can compromise worker performance and elevate accident probability. The significance of environmental factors is particularly pronounced in infrastructure construction projects conducted in mountainous or otherwise challenging terrain, where conditions can change rapidly and unpredictably. Mitropoulos et al. (2005) advanced a systems-based model of construction accident causation that explicitly incorporated environmental conditions as an interacting

element in the accident generation process, arguing that accidents emerge from complex, dynamic interactions among workers, the work system, and the physical environment rather than from simple linear chains of cause and effect.

The preponderance of evidence from the construction safety literature thus supports a multidimensional conceptualization in which human, organizational, managerial, technical, and environmental factors interact dynamically to shape safety outcomes. This complexity underscores the need for systematic, multi-factor assessment approaches rather than reliance on checklist-based evaluations that examine each factor independently. Understanding the interrelationships and relative importance of these factors is essential for developing effective safety management strategies, a need that provides direct motivation for the methodological approach adopted in the present study.

The review of construction safety literature presented in this section, spanning studies of human factors, organizational determinants, technical and site hazards, and the distinctive safety challenges of developing country construction contexts, provides the empirical and conceptual basis for identifying a candidate set of safety factors relevant to irrigation construction projects in Nepal. Drawing on the full breadth of the literature reviewed, a pool of 32 safety factors was identified, covering five categories: Human, Organizational, Managerial, Technical, and Site/Environmental. These categories reflect the multidimensional structure of construction safety established in this section and are consistent with the factor taxonomies employed in comparable quantitative safety assessment studies(Gunduz et al., 2017; Ng et al., 2005; Sawacha et al., 1999; Toole, 2002).

The factors are presented in Table 2.1 below, together with the primary references that support their inclusion. Each factor was included based on empirical evidence of its influence on construction safety performance in one or more peer-reviewed studies, and its face validity as a potentially relevant safety concern in the irrigation construction context. The full set of 32 factors was subsequently subjected to expert content validity assessment, as described in Chapter 3, to confirm the relevance of each factor specifically to irrigation construction projects in Nepal before proceeding to quantitative analysis.

Table 1: Initial pools of factors affecting safety in construction projects

S.N.	Safety Factor	Category	Key References
1	Unsafe worker behavior	Human	Sawacha et al. (1999); Toole (2002)
2	Improper use of PPE	Human	Tam et al. (2004); Ng et al. (2005)
3	Insufficient safety training	Human	Durdyev et al. (2017); Alkilani et al. (2013)
4	Low worker morale	Human	Emma-Ochu et al. (2021); Nawi et al. (2016)
5	Worker fatigue	Human	Mitropoulos et al. (2005); Hinze et al. (2013)
6	Substance use	Human	Hinze et al. (2013); Awwad et al. (2016)
7	Communication barriers	Human	Alkilani et al. (2013); Nawi et al. (2016)
8	Low management commitment towards safety	Organizational	Jannadi & Bu-Khamsin (2002); Rechenthin (2004)
9	Absence of safety policies	Organizational	Kartam et al. (2000); Awwad et al. (2016)
10	Weak safety culture	Organizational	Rivera et al.(2021); Hinze et al. (2013)
11	Insufficient safety budget	Organizational	Awwad et al. (2016); Durdyev et al. (2017)
12	Poor reporting culture regarding accidents and near misses	Organizational	Sawacha et al. (1999); Nawi et al. (2016)
13	Poor documentation of accidents and near misses	Organizational	Bajracharya et al. (2023); Alkilani et al. (2013)
14	Weak safety supervision	Managerial	Toole (2002) ; Jannadi & Bu-Khamsin (2002)
15	Lack of clear safety instructions from the supervisor to workers	Managerial	Emma-Ochu et al. (2021); Liu et al. (2017)
16	Inadequate safety inspections	Managerial	Ng et al. (2005); Hinze et al. (2013)
17	Lack of proper authorization before starting hazardous works	Managerial	Kartam et al. (2000); Tam et al. (2004)

18	Lack of a safety officer	Managerial	Kartam et al. (2000); Tam et al. (2004)
19	Lack of toolbox talks	Managerial	Hinze et al. (2013); Liu et al. (2017)
20	Poor subcontractor management	Managerial	Nawi et al. (2016); Awwad et al. (2016)
21	Inadequate work planning	Managerial	Mitropoulos et al. (2005); Hinze et al. (2013)
22	Poor equipment maintenance	Technical	Mitropoulos et al. (2005); Ng et al. (2005)
23	Improper equipment operation	Technical	Tam et al. (2004); Hinze et al. (2013)
24	Unsafe scaffolding	Technical	Tam et al. (2004); Tixier et al. (2017)
25	Inadequate machine guarding	Technical	Kartam et al. (2000); Pinto et al. (2011)
26	Material handling risks	Technical	Sawacha et al. (1999); Toole (2002)
27	Excavation hazards	Site/Environ.	Mitropoulos et al. (2005); Pinto et al. (2011)
28	Slippery or unstable surfaces	Site/Environ.	Hinze et al. (2013); Tripathi & Shrestha (2018)
29	Poor housekeeping	Site/Environ.	Bajracharya et al. (2023); Rivera et al. (2021)
30	Poor emergency preparedness	Site/Environ.	Ng et al. (2005); Tam et al. (2004);
31	Adverse weather exposure	Site/Environ.	Tripathi & Shrestha (2018); Alkilani et al. (2013)
32	Unsafe site layout	Site/Environ.	Nawi et al. (2016); Sawacha et al. (1999)

2.2 Construction Safety in Developing Countries

The challenge of construction safety takes on a particularly acute dimension in developing and transitional economies, where structural constraints at the institutional, organizational, and individual levels compound the inherent hazards of construction work. Across South Asia, Sub-Saharan Africa, the Middle East, and parts of Latin America,

construction sectors are expanding rapidly in response to urbanization, population growth, and national infrastructure development priorities. This expansion intensifies the pressure on safety systems that are already strained by limited resources, weak institutional governance, and a predominantly informal workforce. The resulting safety performance gap between developed and developing country construction sectors is substantial and persistent, and represents one of the most pressing challenges in global occupational health and safety.

A key structural characteristic that distinguishes construction safety in developing countries is the weakness of the regulatory and enforcement framework. In contrast to high-income countries, where occupational safety regulations are relatively comprehensive and their enforcement is supported by dedicated inspectorates with trained personnel and legal authority, many developing country governments lack both the legislative framework and the institutional capacity to effectively regulate construction site safety. Awwad et al. (2016) reported that inadequate regulatory enforcement was among the most consistently cited barriers to improved safety performance in construction projects across the Middle East, where, despite relatively high levels of investment in infrastructure, safety practices on many sites remained reactive and inconsistent. The situation is compounded by the fragmented nature of the construction industry in developing countries, where a large share of work is executed by small subcontracting firms with limited organizational capacity for formal safety management.

Economic constraints represent a second major structural barrier to improved safety performance in developing country construction. Insufficient safety budgets restrict the availability of personal protective equipment, limit investment in safety training programs, reduce the capacity for independent safety inspection, and compromise the maintenance of safe equipment. Awwad et al. (2016) specifically identified budget inadequacy as among the most significant organizational factors contributing to unsafe conditions on construction sites in the Lebanese context, while Durdyev et al. (2017) found similar patterns across construction projects in Central Asia. The perception among many contractors in developing countries that safety investment represents a cost without a commensurate return on investment, rather than a risk mitigation measure with measurable financial benefits, perpetuates this underfunding

and creates a cycle in which chronic safety underinvestment produces accidents that further strain already limited organizational resources.

The informal character of the construction workforce in developing countries introduces additional challenges. A significant proportion of construction workers in countries such as Nepal, India, and Bangladesh are engaged on informal, day-labor, or short-term contract arrangements that provide no job security, no access to occupational health services, and no formal mechanism for receiving safety training or reporting safety concerns. Alkilani et al. (2013) highlighted that the reliance on unskilled migrant labor, a common feature of construction in developing countries across the Middle East and South Asia, creates a workforce with limited awareness of occupational hazards and minimal leverage to demand safer working conditions. Emma-Ochu et al. (2021) similarly documented how poor communication between supervisors and workers, arising from language barriers, hierarchical management cultures, and the absence of structured safety communication channels, contributes to the normalization of unsafe practices in many developing country construction environments.

Nepal's construction sector reflects many of these broader patterns while also exhibiting some country-specific characteristics that further complicate safety management. The country's Labor Act of 2017 established a legal framework for workers' rights and occupational safety, but enforcement capacity remains limited, particularly in rural and remote areas where a significant share of infrastructure construction occurs. According to the ILO National OSH Profile for Nepal (2022), the country had ratified only 11 of 190 ILO Conventions as of 2021, and the implementation of relevant provisions in ratified conventions is reported to be inconsistent. The construction sector is among the largest employers in Nepal, engaging approximately 13.8% of the total labor force according to the Nepal Labor Force Survey 2017/18, yet systematic data on construction accidents and occupational diseases remain scarce, limiting the ability to quantify the full burden of safety failures.

Bajracharya et al. (2023) underscored that occupational health and safety challenges in Nepal persist due to multiple overlapping factors: gaps in policy implementation, weak enforcement mechanisms, limited institutional capacity for safety training and oversight, and a predominant safety culture among smaller contractors in which production pressure

consistently takes precedence over worker protection. Tripathi and Shrestha (2018) observed that infrastructure projects in Nepal face elevated risk due to the environmental complexity of the mountain terrain, the logistical challenges of operating in remote areas, and the limited availability of technically trained safety personnel. These observations converge on a recognition that improving construction safety in Nepal requires not only technical interventions at the project level but also sustained institutional investment in regulatory capacity, safety education, and the development of a context-appropriate safety management culture.

The overarching lesson from the literature on construction safety in developing countries is that safety challenges in these contexts are not simply a deficit of technical knowledge or equipment but are deeply embedded in economic structures, governance systems, and organizational cultures. Effective responses must therefore be similarly multi-dimensional, combining regulatory reform, capacity building, and the development of practical safety assessment frameworks that are adapted to local conditions and constraints. This contextual imperative directly informs the present study's focus on developing an integrated and context-specific safety assessment framework for irrigation construction projects in Nepal.

2.3 Quantitative Approaches to Construction Safety Assessment

The field of construction safety assessment has undergone significant methodological evolution over the past three decades, driven by recognition that the qualitative and descriptive approaches that dominated early safety research were insufficient for capturing the complexity, multidimensionality, and dynamic character of construction safety phenomena. Traditional methods such as safety checklists, job safety analyses, and accident frequency tabulations remain widely used in practice because of their simplicity and low resource requirements, but they offer limited analytical power for understanding the underlying structure of safety risk or for generating reliable quantitative estimates of safety performance that can inform data-driven management decisions.

Pinto et al. (2011) provided an influential critique of conventional risk assessment methods in construction, arguing that their reliance on simplified single-variable analyses and deterministic assumptions prevents them from adequately representing the complex,

interdependent relationships among safety factors that characterize real construction environments. This critique spurred growing interest in more sophisticated quantitative approaches capable of capturing multiple factors simultaneously, modeling their interactions, and producing outputs that reflect the inherent uncertainty of safety conditions.

Multivariate statistical methods, particularly exploratory factor analysis and principal component analysis, have emerged as important tools for quantitative safety assessment research. These methods enable researchers to identify the latent dimensional structure underlying large sets of observed safety variables, reducing the dimensionality of complex datasets while retaining most of the information they contain. By grouping intercorrelated safety factors into a smaller number of underlying components, these approaches facilitate more interpretable and analytically tractable representations of the safety factor space. Liu et al. (2017) applied factor analysis to a dataset of construction safety leading indicators, demonstrating that a set of nearly thirty individual safety measures could be reduced to a small number of coherent components representing distinct dimensions of safety performance, significantly improving the clarity and utility of the resulting assessment framework.

Fuzzy logic and fuzzy set theory have been increasingly applied in construction safety assessment to address the inherent vagueness and imprecision of expert safety judgments. Unlike classical probability theory, which requires precise numerical inputs, fuzzy logic methods allow for the representation of linguistic assessments and uncertain knowledge in a mathematically rigorous framework. Gürcanli and Müngen (2009) developed a fuzzy risk analysis model for construction sites that demonstrated substantially improved flexibility in handling the imprecise, judgment-based data that typically characterizes safety assessments, particularly in contexts where historical accident data are limited or unavailable. The model enabled the integration of expert knowledge into a quantitative framework without forcing the false precision of classical probability-based approaches. Gunduz et al. (2017) extended this line of inquiry by combining fuzzy methods with structural equation modeling to assess safety performance across construction project phases, demonstrating that the integration of statistical and fuzzy approaches could capture complex multi-directional causal relationships among safety factors that would be invisible to simpler analytical tools.

Structural equation modeling (SEM) represents another significant advancement in quantitative construction safety research. SEM enables the simultaneous estimation of multiple causal relationships among latent and observed variables, providing a powerful framework for testing hypothesized structural models of safety performance. The technique has been applied in construction safety research to examine how organizational factors such as management commitment, safety culture, and communication practices influence both intermediate behavioral outcomes and ultimate accident frequencies. The capacity of SEM to represent indirect and mediated effects, for example, the pathway through which management commitment affects accident rates by first shaping safety culture, which in turn influences worker behavior, makes it particularly valuable for developing theoretically grounded understandings of safety determinants.

Despite these methodological advances, a significant limitation of many existing quantitative approaches is their predominantly deterministic character. Most models in the construction safety literature produce single-point estimates of safety performance that do not reflect the range of outcomes that may realistically be expected given the inherent variability of construction environments. Tixier et al. (2017) argued that this deterministic orientation is a fundamental shortcoming and that safety models should instead be designed to represent the probability distributions of possible safety outcomes rather than single expected values. The ability to characterize not only the most likely safety level but also the range and likelihood of better and worse outcomes provides decision-makers with a far richer basis for risk-informed planning and resource allocation. This argument for probabilistic safety assessment provides the methodological foundation for the simulation-based approach adopted in the present study.

2.4 Factor Structuring and Dimensionality Reduction

Construction safety research characteristically involves the simultaneous consideration of a large number of potentially relevant variables, reflecting the multidimensional nature of safety phenomena in complex project environments. When safety questionnaire surveys or observational studies collect data on twenty, thirty, or more individual safety factors, the resulting dataset contains substantial intercorrelation among variables, since many factors that influence safety tend to co-vary in predictable ways. For example, organizations with weak safety policies tend also to have insufficient safety training programs, poor reporting cultures,

and inadequate budgets for protective equipment, suggesting that these variables, while conceptually distinct, reflect a common underlying organizational safety orientation. Attempting to analyze such a dataset at the level of individual variables leads to redundancy, analytical inefficiency, and difficulty distinguishing the distinctive safety dimensions that drive project outcomes.

Principal Component Analysis (PCA) is the most widely applied technique for addressing this challenge. PCA is a multivariate statistical technique that transforms a set of intercorrelated variables into a smaller number of uncorrelated linear combinations, known as principal components, that successively capture the maximum remaining variance in the dataset. The technique was introduced by Pearson (1901) and formalized by Hotelling (1933), and has since been applied across an extraordinary range of scientific and social scientific disciplines. In construction management research, PCA has been employed for factor structuring in domains ranging from project success factors and delay analysis to productivity assessment and safety management.

The application of PCA to construction safety data follows a standard sequence. Before analysis, the suitability of the dataset for factor reduction is assessed through the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy which quantifies the proportion of variance among variables that might be caused by underlying factors and through Bartlett's Test of Sphericity, which tests the null hypothesis that the correlation matrix among variables is an identity matrix (i.e., that there is no significant intercorrelation suitable for factor extraction). A KMO value exceeding 0.70 and a statistically significant Bartlett's test together provide the threshold for proceeding with factor extraction. Components are then extracted based on eigenvalue criteria; commonly, only components with eigenvalues greater than 1.0 are retained, because such components explain more variance than any single original variable. Rotation methods, particularly orthogonal rotation using the Varimax algorithm, are subsequently applied to the retained component solution to achieve a cleaner, more interpretable factor structure in which each original variable loads highly on one component and minimally on others.

Rivera et al. (2021) conducted a systematic categorization of safety factors influencing construction projects, drawing on a comprehensive literature review to identify the major types

and categories of safety determinants and their relationships. Their work demonstrated that safety factors could be meaningfully organized into a hierarchical dimensional structure reflecting underlying commonalities in their causal mechanisms, providing a structured conceptual framework that PCA-based empirical analyses can be used to validate and refine. Similarly, Liu et al. (2017) applied factor analysis to construction safety leading indicators, demonstrating that the identified components provided not only a more parsimonious representation of the data but also a more theoretically coherent basis for developing safety intervention priorities, since interventions targeting a component-level dimension could be expected to simultaneously influence all of the individual factors loading on that component.

An important methodological consideration in the application of PCA to construction safety data concerns the handling of cross-loading variables, those that load substantially on more than one extracted component. Such cross-loadings indicate that the variable in question reflects aspects of more than one underlying safety dimension, complicating interpretation. Standard practice in factor analysis is to assign each variable to the component on which its loading is highest; in some cases, variables with genuinely ambiguous loading patterns may be excluded from the final factor solution to improve the clarity and interpretability of the component structure. This exclusion is not a methodological failure but rather a reflection of the genuine conceptual overlap that exists among some safety factors, and it results in a more analytically tractable factor solution that can more effectively support subsequent prioritization and index development.

Beyond its analytical utility, factor structuring through PCA also has important practical implications. By identifying the underlying dimensions of construction safety performance, factor analysis results can guide the development of targeted and efficient safety intervention strategies. Rather than addressing each of twenty-seven or thirty individual safety factors independently, a practically infeasible approach given typical resource constraints, safety managers can focus their attention on the few underlying dimensions that collectively drive the observed pattern of safety factor occurrence on their projects. This dimension-level perspective is more strategically actionable and more resource-efficient than a purely variable-level approach to safety improvement.

2.5 Prioritization of Safety Factors Using Multi-Criteria Decision-Making

Once safety factors have been identified, validated, and organized into a coherent dimensional structure, a critical subsequent step is the determination of their relative importance in contributing to overall safety performance. Not all safety factors exert equivalent influence on safety outcomes; some are more consequential, more prevalent, or more controllable than others, and an effective safety management strategy requires an understanding of these differences to allocate limited managerial attention and financial resources where they will have the greatest impact. The prioritization of safety factors is therefore not merely an academic exercise but a practical prerequisite for the development of evidence-based, resource-efficient safety management programs.

The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty in the 1970s, is the most widely applied method for multi-criteria decision making in construction safety research, and more broadly across engineering, business, and public policy domains. AHP is grounded in the mathematical principle that complex decisions involving multiple criteria can be decomposed into a hierarchical structure and resolved through a systematic process of pairwise comparison among elements at each level of the hierarchy. The method exploits the well-established cognitive capacity of human experts to make reliable relative judgments when comparing two elements at a time, even in contexts where the direct quantification of absolute importance values would be highly uncertain or subjective. By eliciting a complete set of pairwise comparisons from a decision-maker or group of experts, AHP constructs a comparison matrix from which priority weights are derived through the calculation of the principal eigenvector, providing a mathematically coherent representation of the relative importance of all evaluated criteria.

A particularly valuable feature of the AHP framework is its built-in mechanism for evaluating the logical consistency of the pairwise judgments provided by respondents. Human experts making a large number of pairwise comparisons are prone to transitivity violations, situations in which, for example, a respondent judge’s factor A to be more important than factor B, and factor B to be more important than factor C, but also judges factor C to be more important than factor A. Such inconsistencies, if they are sufficiently large, indicate that the respondent's judgments do not reflect a coherent underlying preference structure and should

be treated with caution. AHP addresses this concern through the Consistency Ratio (CR), which measures the degree of inconsistency in a comparison matrix relative to the degree of inconsistency that would be expected from a matrix of random judgments. A CR below 0.10 is the conventionally accepted threshold for acceptable consistency, indicating that any inconsistencies in the judgment matrix are minor and likely reflect normal human judgment variability rather than fundamental incoherence.

Jannadi and Bu-Khamsin (2002) applied a systematic importance-weighting approach to construction safety factors in the Saudi Arabian industrial construction context, demonstrating that factors related to site management, supervision quality, and safety program implementation were among the highest-ranked determinants of safety performance. Their findings underscored the importance of organizational and managerial factors relative to purely technical ones, a pattern that has since been replicated in numerous subsequent studies. Rechenthin (2004) extended this argument by demonstrating that organizations that systematically prioritize safety-related practices and integrate safety performance metrics into their broader project management systems achieve not only better safety outcomes but also measurable improvements in overall project efficiency and competitive positioning.

Shah and Pipaliya (2024) applied an AHP-based prioritization framework to construction safety factors in the Indian context, producing a ranked set of safety factors that reflected the specific characteristics of the South Asian construction environment, including the prominence of training deficiencies and supervision inadequacies as top-ranked risk drivers. Similarly, Subbaiah et al. (2025) developed an integrated AHP-fuzzy TOPSIS approach for safety factor prioritization, combining the consistency-checking strengths of AHP with the linguistic uncertainty handling capabilities of fuzzy methods to produce priority weights that were more robust to the imprecision of expert input than those derived from classical AHP alone. These more recent applications reflect a growing trend toward hybrid analytical approaches that leverage the complementary strengths of multiple methods to produce more defensible and informative prioritization outcomes.

The application of AHP to the prioritization of validated safety factors in the present study is grounded in several advantages specific to the research context. First, AHP is particularly well-suited to situations in which quantitative performance data are limited or

unavailable, since it relies on comparative expert judgment rather than requiring objective measurement of factor impacts. In the context of irrigation construction safety in Nepal, where systematic accident data are scarce, this characteristic is a significant practical advantage. Second, the structured nature of the AHP process produces a transparent and auditable record of the basis for priority weights, enabling stakeholders to review and, if necessary, challenge the assumptions underlying the prioritization. Third, the consistency ratio mechanism provides an objective basis for evaluating the reliability of the expert judgments collected, enhancing the credibility of the resulting weight estimates.

2.6 Uncertainty in Construction Safety Assessment

Construction project environments are inherently characterized by variability and uncertainty across all dimensions of project execution, and safety performance is no exception. The frequency with which specific safety hazards are encountered on a given project depends on a complex and dynamic combination of factors, including the composition and experience level of the workforce, the quality and consistency of supervision, the prevailing weather and terrain conditions, the condition and adequacy of equipment and protective systems, and the organizational culture and management practices of the contracting firms involved. Because these determinants vary across projects, across project phases within a single project, and across different seasons and site conditions, any fixed deterministic estimate of safety performance necessarily understates the true variability in safety conditions that project stakeholders must anticipate and manage.

Tixier et al. (2017) provided a compelling theoretical and empirical case for the incorporation of uncertainty into construction safety assessment, arguing that the deterministic orientation of most existing assessment models produces systematically misleading results by presenting single-point estimates as if they were precise and reliable forecasts of what will actually occur on a project. In reality, the deterministic estimate represents only one point in a distribution of possible outcomes, and the shape and spread of that distribution, which is essential for understanding the real risk profile of a project, is invisible in deterministic analyses. Tixier et al. (2017) demonstrated through an analysis of machine learning-based accident prediction models that the predictive uncertainty in safety outcomes was substantial,

reinforcing the argument that probabilistic approaches provide a more complete and honest representation of safety risk.

The sources of uncertainty in construction safety assessment can be categorized into two broad types: aleatory uncertainty, which arises from the genuine randomness and variability of the phenomena being studied and cannot be reduced by collecting more information; and epistemic uncertainty, which arises from limitations in knowledge and data availability and can, in principle, be reduced through additional research or measurement. In practical construction safety assessment, both types of uncertainty are present. Aleatory uncertainty manifests in the day-to-day variability of safety-relevant behavior and conditions on construction sites, reflecting the genuine stochasticity of human behavior and environmental conditions. Epistemic uncertainty arises from the limited and often subjective nature of the data available to estimate the frequency and severity of safety factor occurrence, particularly in developing country contexts where systematic accident records are sparse and expert judgments must substitute for empirical data.

Representing uncertainty through probability distributions rather than fixed values is the central methodological innovation that distinguishes probabilistic safety assessment from its deterministic counterpart. A triangular distribution, defined by three parameters: the minimum plausible value, the most likely value, and the maximum plausible value, is particularly well suited to contexts where data are limited and expert judgment must be the primary source of distributional information. The triangular distribution has been widely used in construction risk assessment and Monte Carlo simulation studies because it is intuitive and easily parameterized by expert elicitation, requiring only that experts specify the range and mode of a variable rather than fitting a precise statistical distribution to empirical data. The minimum and maximum values bound the range of plausible outcomes, while the mode represents the expert's best estimate of the most commonly encountered value, providing a simple three-point characterization that can be readily obtained through structured questionnaire surveys.

The recognition that safety performance is subject to meaningful uncertainty has important implications for decision-making. When safety assessment produces only a single deterministic index value, project managers cannot distinguish between a scenario in which

that value reflects a narrow range of possible outcomes and one in which the same expected value conceals a wide distribution stretching from dangerously unsafe to highly safe. This ambiguity is decision-relevant: a project with a moderate expected safety index but a high probability of very poor safety outcomes requires fundamentally different management attention than a project with the same expected index but a tightly clustered distribution around that central value. Probabilistic assessment makes this distinction visible and actionable, enabling more appropriately calibrated safety management responses.

2.7 Simulation-Based Risk Assessment

Monte Carlo Simulation (MCS) is the most widely applied simulation-based technique for probabilistic risk and safety assessment in construction project management, and has become an indispensable tool in quantitative risk analysis across engineering, finance, environmental science, and public policy domains. The method takes its name from the Monte Carlo casino in Monaco, a reference to its reliance on random sampling, and was formally developed in the 1940s by mathematicians working on nuclear weapons research who needed a practical method for calculating the behavior of complex stochastic systems that were analytically intractable. Since its introduction to project management in the 1960s, MCS has been applied to an expanding range of problems, including cost estimation, schedule risk analysis, reliability assessment, and, most recently, safety performance evaluation.

The operational logic of Monte Carlo Simulation is straightforward. For each variable in a quantitative model whose value is uncertain, a probability distribution is defined that represents the range and likelihood of different values that the variable might take. In each simulation run, a random value is drawn from each variable's distribution, and the model is evaluated using that combination of values to produce a single output result. This process is repeated a large number of times, typically between 10,000 and 100,000 iterations in modern implementations, each time producing a slightly different output result reflecting a different combination of randomly sampled input values. The collection of output results across all iterations constitutes a probability distribution for the output variable, providing information not only about the expected or most likely value but also about the full range and probability of different outcomes.

In the context of construction safety assessment, MCS allows the variability in safety factor occurrence frequencies to be propagated through a quantitative safety index model to yield a probability distribution over possible safety performance levels. This capability directly addresses the limitation of deterministic safety assessment identified in the preceding section, transforming a single-point safety estimate into a rich probabilistic characterization of the range and likelihood of safety conditions. Tixier et al. (2017) demonstrated the power of this approach in construction safety research, showing that simulation-based analysis could reveal patterns of safety risk variation that were completely invisible to deterministic methods, including the identification of low-probability but high-consequence safety scenarios that would be systematically underestimated by approaches relying solely on expected values.

The triangular distribution is the most commonly employed probability distribution in construction risk simulation studies that rely on expert-elicited input parameters, and its use in the present study is consistent with established best practice in this literature. The distribution's three-parameter structure, minimum, mode, and maximum, maps directly onto a standard format of expert elicitation in which respondents are asked to specify the lowest plausible value, their best estimate of the typical value, and the highest plausible value for each input variable. This elicitation format is cognitively accessible for construction professionals who may not have formal statistical training, and the resulting distributions, while simple, capture the essential uncertainty characteristics of each input in a way that has been shown to produce reasonable simulation results across a wide range of construction risk applications.

The number of simulation iterations required to achieve stable and reliable results depends on the complexity of the model and the precision required for the output statistics. For construction safety index models of the type employed in the present study, involving the weighted summation of a moderate number of independently sampled input variables, convergence to stable output statistics is typically achieved with 10,000 or more iterations. Modern computational tools, including widely available spreadsheet-based simulation add-ins such as @RISK and Crystal Ball, as well as open-source platforms such as Python's NumPy and SciPy libraries, make it straightforward to execute simulations of this scale in seconds, removing any practical barrier to the routine use of MCS in construction safety research and practice.

The outputs of the Monte Carlo Simulation can be interpreted and communicated in several complementary ways. The probability density and cumulative distribution functions of the Safety Index provide a complete visual characterization of the distribution of possible safety outcomes and their associated probabilities. Summary statistics, including the mean, median, standard deviation, and selected percentile values (e.g., the 5th, 50th, and 95th percentiles), provide a concise numerical summary of the distribution's central tendency and spread. When safety level thresholds are defined, distinguishing, for example, between unsafe, moderate, and safe safety performance levels, the proportion of simulation iterations falling within each category provides a direct estimate of the probability that the project falls within each category, offering an immediately actionable characterization of the risk profile for use by project managers and safety stakeholders.

2.8 Safety Factor Validation Using the Content Validity Index

Before quantitative safety factors can be reliably used in an analytical framework, it is essential to establish that they are genuinely relevant and applicable to the specific project context being studied. This validation step is particularly important in sector-specific studies such as the present one, where safety factors identified from the general construction safety literature may not all be equally pertinent to the distinctive characteristics of irrigation construction projects. A factor that is critical in high-rise building construction, such as fall protection from upper floors, may be of limited relevance in excavation-dominated irrigation projects, while factors related to water exposure and soil instability that are central to irrigation construction may be absent or underemphasized in general-purpose safety factor frameworks.

The Content Validity Index (CVI) is a widely used expert-judgment-based method for evaluating the relevance and representativeness of survey items or assessment factors in a given measurement context. The method was originally developed in the health and nursing research literature as a means of ensuring that measurement instruments accurately reflect the domain they purport to assess, and has since been adapted for use in engineering and construction management research as a technique for validating the relevance of assessment criteria to specific project contexts. The CVI is calculated for each factor as the proportion of expert panelists who rate the factor as relevant or highly relevant to the study context, typically using a four-point rating scale in which ratings of 3 or 4 are coded as indicating relevance and

ratings of 1 or 2 as indicating non-relevance. A factor is typically retained for further analysis if its CVI exceeds a predetermined threshold, commonly set at 0.78 for panels of six or more experts, reflecting acceptable levels of inter-rater agreement on item relevance.

The strength of the CVI method lies in its ability to leverage the domain expertise of experienced practitioners to make contextually informed judgments about factor relevance that are difficult to capture through purely bibliometric or statistical approaches. Expert panelists with direct experience in irrigation construction project management are well-positioned to distinguish between safety factors that are commonly encountered and genuinely consequential in this context and those that, while theoretically relevant to construction safety in general, are of limited practical importance in irrigation projects specifically. This expert-grounded validation process ensures that the subsequent analytical framework is built on a foundation of contextually appropriate and practically meaningful safety factors, rather than on a collection of factors whose relevance is assumed rather than demonstrated.

2.9 Research Gap

The review of existing literature presented in the preceding sections reveals a substantial and growing body of research on construction safety that spans multiple methodological approaches, geographic contexts, and analytical scales. This body of work has produced important contributions to understanding the determinants of construction safety performance, the methodological challenges of quantitative safety assessment, and the particular difficulties faced by developing country construction sectors. Taken together, these contributions provide a strong conceptual and methodological foundation on which the present study builds. However, the review also reveals four persistent and practically significant gaps that motivate the specific research design adopted here.

The first and most sector-specific gap concerns the limited scholarly attention given to irrigation construction projects as a distinct and high-risk construction sub-sector. Despite the importance of irrigation infrastructure for food security and rural development in countries such as Nepal, and despite the distinctive safety risk profile of irrigation construction, characterized by extensive excavation, water-related hazards, slope instability, and operations in remote terrain, the volume of safety research addressing this sub-sector specifically is

strikingly limited. Among the few studies that have engaged with this context, Tamara et al. (2020) identified potentially hazardous risk sources across work components of irrigation channel construction, including earthworks, canal lining, and hydraulic structure installation; Baso et al. (2024) evaluated occupational safety implementation in the Wawotobi Irrigation Area rehabilitation project and found that safety compliance was inconsistent and did not meet required standards; and Mishra and Aithal (2021) documented the significant occupational hazards, including rockfall, landslide risk, and toxic gas exposure, present in irrigation tunnel construction in Nepal. Notwithstanding these contributions, none provides a comprehensive, integrated, quantitative safety assessment framework specifically designed and validated for irrigation construction, and none addresses the Nepalese context with the methodological depth required to support evidence-based safety management in this sector.

The second gap pertains to the methodological limitations of safety assessment approaches currently applied in the Nepalese construction industry. As Pinto et al. (2011) observed, prevailing risk assessment methods tend to rely on simplified checklists and deterministic, single-variable analyses that do not adequately represent the complex, interdependent relationships among safety factors characteristic of real construction environments. In Nepal, the informal nature of safety management, with reliance on experience-based judgment rather than structured, evidence-based systems, further limits the ability to make defensible, data-driven decisions about where to direct safety investments and management attention. This methodological gap is particularly consequential in the irrigation construction sector, where the absence of structured safety assessment frameworks leaves project managers without a reliable basis for prioritizing safety interventions or benchmarking safety performance.

The third gap concerns the integration of multiple complementary analytical methods within a unified safety assessment framework. Individual methods, content validity assessment, principal component analysis, the Analytic Hierarchy Process, and Monte Carlo Simulation, have each been applied in construction safety research, but their systematic integration within a single coherent study, following a logically ordered sequence from expert-validated factor identification through dimensional structuring, prioritization, and probabilistic safety index assessment, has not been demonstrated in the context of irrigation construction in

a developing country. The fragmented application of these methods in isolation limits the analytical depth and practical utility of existing safety assessment approaches.

The fourth gap is quantitative and probabilistic: existing studies on construction safety in Nepal have not produced a comprehensive, numerically grounded assessment of the overall safety performance level of irrigation construction projects that explicitly incorporates the uncertainty inherent in real-world construction environments. Without such an assessment, project managers and policymakers lack a defensible reference point for evaluating current safety conditions, tracking improvement over time, or communicating safety risk to project owners and regulatory authorities in terms that can support resource allocation decisions.

The present study is explicitly designed to address these four interconnected gaps. By applying an integrated multi-method framework, encompassing CVI-based expert validation, PCA-based factor structuring, AHP-based prioritization, Safety Index formulation, and Monte Carlo Simulation, to the specific context of irrigation construction projects in Nepal, the study contributes both a methodological advance and a body of empirical findings that directly serve the need for sector-specific, context-appropriate, and uncertainty-aware safety assessment. The practical motivation is equally important: the findings are intended to provide project managers, contractors, government project owners, and regulatory authorities with a validated, quantitative, and actionable basis for safety improvement in a sector that carries direct consequences for worker welfare and national development goals.

CHAPTER 3: METHODOLOGY

3.1 Research Design

This study adopts a quantitative, sequential multi-method research design to develop and apply a comprehensive safety performance assessment framework for irrigation construction projects in Nepal. The quantitative approach is appropriate for this research because it enables the systematic collection of numerical data from a structured survey instrument, the application of statistical and mathematical analytical techniques to derive safety factor structures and priority weights, and the generation of probabilistic simulation-based outputs that can be objectively interpreted and compared. The sequential design reflects the logical dependency among the analytical stages of the study: each stage builds directly on the outputs of the preceding one, producing an integrated analytical pipeline from initial factor identification through to final probabilistic safety classification.

The study follows five principal methodological stages arranged in a logical progression. In the first stage, safety factors influencing construction safety performance are identified through a systematic review of peer-reviewed literature. In the second stage, these factors are subjected to expert validation using the Content Validity Index (CVI) method to confirm their relevance and applicability to the specific context of irrigation construction projects. In the third stage, data collected through a structured questionnaire survey of experienced construction professionals are analyzed using Principal Component Analysis (PCA) to identify the underlying dimensional structure of the validated safety factors. In the fourth stage, the Analytic Hierarchy Process (AHP) is applied to derive priority weights for the validated safety factors based on expert pairwise comparisons. In the fifth stage, a composite Safety Index is formulated and evaluated probabilistically using Monte Carlo Simulation, with results interpreted through a predefined safety level classification framework. The overall research design is illustrated in Figure 3.1.

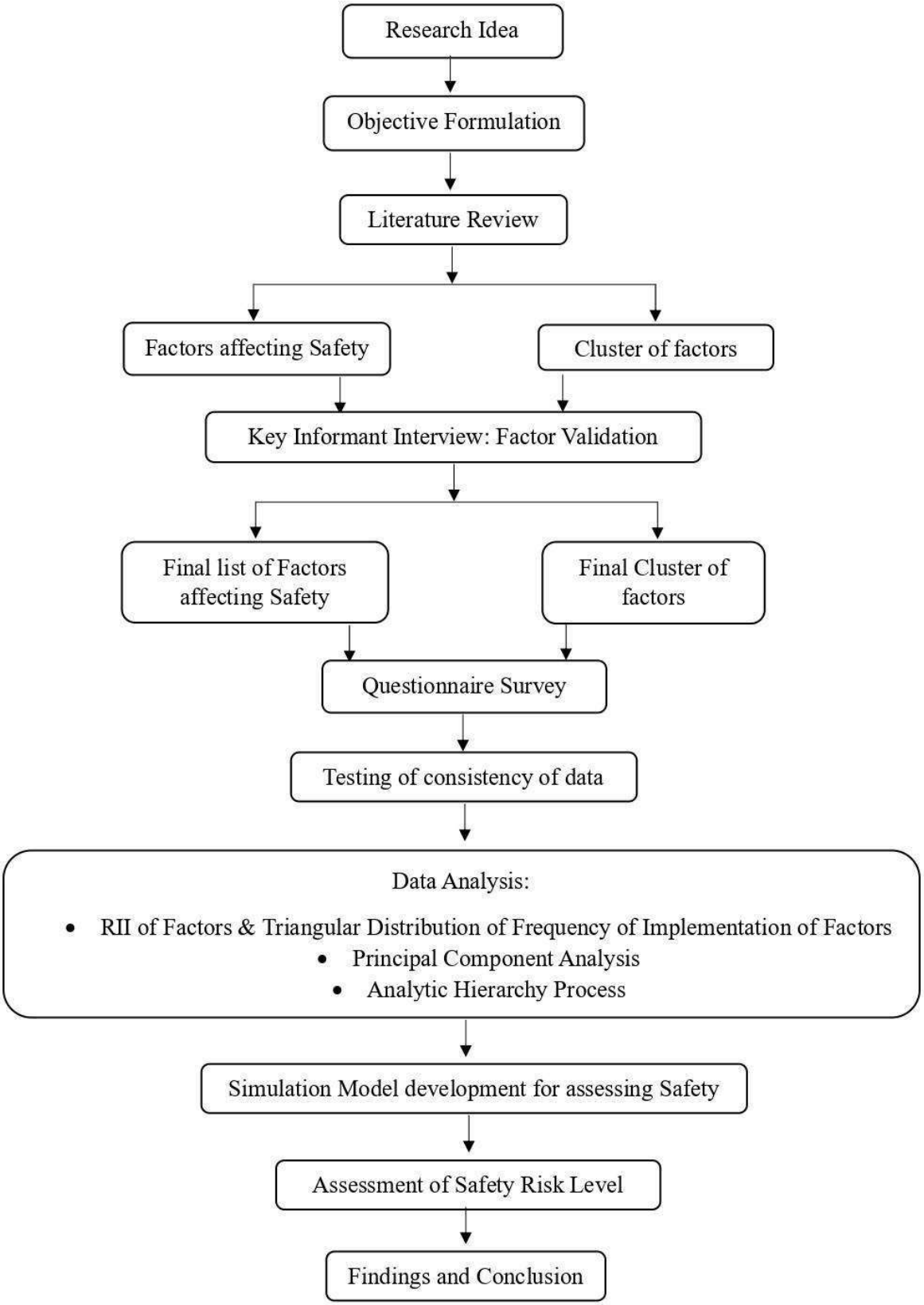

Figure 1: Research Design

This integrated design is deliberately structured to ensure that the analytical outputs at each stage are grounded in both empirical data and expert judgment, and that the final safety assessment reflects the genuine complexity and variability of safety conditions in irrigation construction projects. By combining statistical dimensionality reduction, structured multi-criteria decision making, and probabilistic simulation within a single coherent framework, the study advances beyond the methodological limitations of single-method approaches that have characterized much of the existing literature in this area.

3.2 Study Area

The study focuses on irrigation construction projects being implemented under the Department of Water Resources and Irrigation in Nepal. Nepal is a landlocked South Asian country situated in the central Himalayan region, bordered by China to the north and India to the south, east, and west. Geographically, the country is divided into three broad ecological zones from south to north: the flat Terai plains, the mid-hill region characterized by undulating topography and river valleys, and the high-mountain zone of the Himalayas. This diversity in terrain creates markedly different construction environments across the country, with the Terai supporting extensive canal-based irrigation systems on flat agricultural land and the mid-hills requiring slope-stabilization works, headworks at river intakes, and tunneling for irrigation conveyance.

Irrigation infrastructure is a strategic national priority in Nepal, given the country's heavy dependence on agriculture, which contributes approximately 24% of gross domestic product and provides livelihoods for the majority of the rural population. The Department of Water Resources and Irrigation (DWRI) under the Ministry of Energy, Water Resources and Irrigation manages the planning, construction, and rehabilitation of irrigation systems across all three ecological zones, including surface irrigation schemes, groundwater development projects, and farmer-managed irrigation systems. As of the time of this study, a significant number of irrigation construction and rehabilitation projects were underway across the mid-hill and Terai regions, including projects under the Irrigation and Water Resource Management Project and various donor-funded schemes.

The study does not restrict itself to a single project or district; rather, it considers the full spectrum of active irrigation construction projects in Nepal as its study domain, with respondents drawn from across multiple project locations. This broad geographic coverage ensures that the safety factors identified and the safety performance assessment generated are representative of irrigation construction conditions across the country as a whole, rather than reflecting the idiosyncratic characteristics of any single project site.

3.3 Population and Sampling

The target population for this study comprised construction professionals, including project managers, site engineers, contractors, and consultants, with direct experience in the execution of irrigation construction projects in Nepal. This population encompasses individuals employed by government project implementation offices, consulting firms engaged in irrigation project supervision, and contractors actively involved in the construction of irrigation infrastructure. Given the sector-specific focus of the study, only professionals with practical involvement in irrigation or comparable water resources infrastructure construction were considered eligible respondents.

3.3.1 Sampling Technique

Purposive sampling was employed as the primary sampling strategy. Purposive sampling is a non-probability technique in which respondents are selected based on the researcher's judgment that they possess the domain knowledge, experience, and sectoral familiarity necessary to provide reliable and meaningful responses to the survey instrument. This technique is widely adopted in construction management research when the target population is a specialist community with specific professional expertise, and when obtaining a comprehensive sampling frame is not practically feasible. In this study, eligibility for inclusion required experience in construction project execution or management and direct involvement in at least one irrigation, water resources, or comparable infrastructure project in Nepal. Respondents were identified through professional networks, contacts in government project offices and consulting firms, and snowball referrals from initial respondents.

3.3.2 Sample Size Determination

Since the precise size of the target population of irrigation construction professionals in Nepal is not registered or bounded, the population is effectively infinite for sampling purposes. The sample size was determined using the standard formula for estimating a proportion from an infinite population. This formula yields the minimum number of respondents required to achieve a stated level of statistical precision at a given confidence level:

$$n = Z^2 \times p(1-p) / e^2 \quad \text{.... (Eq. 3.1)}$$

where n is the required sample size; Z is the Z-score corresponding to the desired confidence level; p is the estimated proportion of the population with the characteristic of interest (assumed to be 0.50, which maximizes the required sample size and therefore provides the most conservative estimate); and e is the acceptable margin of error.

For this study, a confidence level of 90% was selected, corresponding to a Z-score of 1.645. A margin of error of 10% (e = 0.10) was deemed appropriate, reflecting the professional specialist character of the target population and the practical constraints on data collection in a geographically dispersed sector. Substituting these values:

$$n = 67.65 \approx 68$$

The calculated minimum sample size is 68. Accordingly, the study targeted a minimum of 68 valid responses for the main questionnaire survey. A total of 100 questionnaires were distributed to provide a margin for non-response and incomplete responses. After screening for completeness and eligibility, 68 fully completed and valid responses were retained for analysis, exactly meeting the minimum required sample size and providing a statistically adequate basis for PCA, AHP, and Monte Carlo Simulation at a 90% confidence level with a ±10% margin of error.

3.4 Methods of Data Collection

This study employed both secondary and primary data collection methods, drawing on each to serve distinct analytical purposes.

3.4.1 Primary Data

Primary data were collected through a structured questionnaire survey administered to eligible construction professionals. The questionnaire was designed to collect two types of information about each validated safety factor: (i) the importance or significance of the factor in influencing safety performance on irrigation construction projects; and (ii) the frequency of occurrence of the factor on such projects as observed by the respondent. A copy of the full questionnaire instrument, including all survey sections and rating scales, is provided in Annex 2.

The questionnaire comprised three sections. Section A collected demographic and professional background information from respondents, including their professional role, years of experience, and the types of irrigation construction projects in which they had been involved; this information was used to verify respondent eligibility and to characterize the survey sample. Section B presented the validated safety factors and asked respondents to rate the importance of each factor on a five-point Likert scale from 1 (Not Important) to 5 (Extremely Important). Section C asked respondents to rate the frequency of occurrence of each safety factor on irrigation construction sites on a five-point Likert scale from 1 (Never) to 5 (Always). Before full distribution, the questionnaire was pilot-tested with a small group of construction professionals; minor wording revisions were made on the basis of pilot feedback before the final version was deployed.

In addition to the main questionnaire, a structured pairwise comparison instrument was used to collect data for the AHP analysis. Eligible respondents, those with senior professional experience in irrigation project execution or management, were presented with pairwise comparison matrices for the safety components and individual factors identified through PCA, and asked to compare pairs of elements using Saaty's (1980) nine-point scale. This instrument was administered separately from the main questionnaire, typically through in-person or scheduled interview sessions to facilitate clarification of any judgment inconsistencies.

Survey distribution was carried out through professional networks, government project offices, and irrigation sector consulting firms, with both in-person and digital response formats provided to maximize response rates. Respondents were assured of the confidentiality of their individual responses, and no personally identifying information was requested beyond professional role and years of experience.

3.4.2 Secondary Data

Secondary data were collected through a systematic review of peer-reviewed journal articles, conference proceedings, technical reports, government policy documents, and ILO publications relevant to construction safety, occupational health and safety in Nepal, irrigation project management, and quantitative safety assessment methodologies. The review covered literature published between 1999 and 2025, accessed through databases including Scopus, Web of Science, Google Scholar, and ASCE's online library. The secondary data review served two purposes: first, to identify the initial pool of 32 candidate safety factors (presented in Table 2.1 of Chapter 2); and second, to provide the theoretical and empirical foundation for each stage of the analytical framework, as documented throughout Chapters 2 and 3. The expert validation questionnaire used for Content Validity Index assessment of the initial safety factors was also developed on the basis of this secondary data review.

3.5 Data Analysis

The data collected through the questionnaire survey were analyzed using a three-stage statistical and simulation-based procedure, corresponding to the three core quantitative methods of the study: Principal Component Analysis, the Analytic Hierarchy Process, and Monte Carlo Simulation. Each stage is described in turn below.

3.5.1 Principal Component Analysis

Principal Component Analysis (PCA) was applied to the importance ratings data collected in Section B of the questionnaire to identify the underlying dimensional structure of the validated safety factors. Before component extraction, the suitability of the dataset for PCA was assessed using two standard diagnostics. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was computed; a value exceeding 0.70 confirms that the proportion of

shared variance among variables is sufficient to support meaningful factor extraction. Bartlett's Test of Sphericity was also conducted; a statistically significant result ($p < 0.05$) confirms that the correlation matrix is significantly different from an identity matrix, verifying that the variables are sufficiently intercorrelated for PCA to be appropriate.

Component extraction was performed using the principal component method. Components with eigenvalues greater than 1.0 were retained in accordance with the Kaiser criterion, supplemented by inspection of the scree plot. Varimax orthogonal rotation was applied to the retained solution to improve interpretability. Variables with a rotated factor loading of 0.40 or above were assigned to the component on which their loading was highest; variables with substantial cross-loadings on two or more components were reviewed and, where necessary, excluded to preserve structural clarity. The retained components were labeled according to the substantive content of their highest-loading factors, and the cumulative variance explained was reported as an indicator of solution adequacy.

3.5.2 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) was applied to derive quantitative priority weights for the validated safety factors. A two-level hierarchy was constructed: at the first level, pairwise comparisons were made among the five PCA-derived safety components; at the second level, pairwise comparisons were made among the individual factors within each component. Priority weights were derived at each level using the eigenvector method, and global factor weights were computed by multiplying local component weights by local factor weights within each component, yielding a single set of globally normalized weights summing to unity across all factors.

The logical consistency of each pairwise comparison matrix was evaluated using the Consistency Ratio (CR), calculated as:

$$\mathbf{CI = (\lambda max - n) / (n - 1) \quad ... (Eq. 3.2)}$$

where λmax is the principal eigenvalue of the comparison matrix, n is the matrix order, and RI is the Random Consistency Index tabulated by Saaty (1980) for matrices of the same order. A CR value at or below 0.10 was accepted as indicating satisfactory consistency.

Matrices exceeding this threshold were returned to respondents for revision before being incorporated into weight calculations.

3.5.3 Monte Carlo Simulation and Safety Index

A composite Safety Index (SI) was formulated to integrate the AHP-derived global factor weights with the frequency of occurrence data collected in Section C of the questionnaire. The Safety Index is expressed as:

$$\mathbf{SI = \Sigma\ (w_i \times f_i) \quad for\ i = 1\ to\ n \quad ...\ (Eq.\ 3.3)}$$

where w_i is the AHP-derived global weight of the i^{th} safety factor, and f_i is the normalized occurrence frequency of that factor. To incorporate the uncertainty inherent in the frequency ratings, a Monte Carlo Simulation was applied over 10,000 iterations. For each factor, a triangular probability distribution was defined using the minimum, mode, and maximum observed frequency ratings across survey respondents. In each simulation iteration, a random value was independently sampled from each factor's triangular distribution, normalized to the [0, 1] scale, and substituted into Equation 3.3 to yield a single simulated Safety Index value. The MATLAB Code used for the simulation is provided in Annex 1. The 10,000 resulting values constitute a probability distribution over possible safety performance outcomes, from which summary statistics and safety level probabilities are derived.

To facilitate the practical interpretation of the simulated Safety Index values, a three-tier safety level classification framework was established. The three levels, Unsafe, Moderate, and Safe, are defined based on threshold values of the normalized Safety Index scale. These thresholds were derived from a review of comparable composite safety index studies in the construction management literature and calibrated to reflect the range of Safety Index values that would be expected to correspond to substantially different levels of safety management effort and risk burden. The details are tabulated in the table 2 below.

Table 2: Safety Level Classification Framework

Safety Level	Safety Index Range	Interpretation
Unsafe	$SI < 0.4$	High burden of frequently occurring safety risk factors across multiple dimensions; immediate and substantial intervention required.
Moderate	$0.4 \leq SI \leq 0.7$	Moderate safety risk burden; safety measures partially in place but insufficiently implemented; targeted improvement required in the highest-weighted safety factor categories.
Safe	$SI > 0.7$	Low burden of safety risk factors; current safety management practices are broadly effective; routine monitoring and continuous improvement are recommended.

By classifying each of the 10,000 simulated Safety Index values into one of these three categories, the simulation results are converted into probability estimates for each safety level, providing decision-makers with a directly actionable risk profile that goes beyond the single-point deterministic estimate provided by conventional safety assessment approaches.

3.6 Data Reliability

The reliability of the survey data was assessed using Cronbach's Alpha coefficient, which measures the internal consistency of responses across items in each survey section. Cronbach's Alpha ranges from 0 to 1, with higher values indicating stronger consistency. A value of 0.70 or above is conventionally accepted as indicating satisfactory reliability for social science and engineering survey instruments (Nunnally, 1978). In this study, Cronbach's Alpha was calculated separately for the importance ratings section and the frequency of occurrence section to verify that respondents were answering consistently across all items within each section, and that the scale items within each section were measuring the same underlying construct.

In addition to internal consistency, the content validity of the factor set was established through the CVI procedure described in Section 3.1. An S-CVI of 0.90 or above for the retained factor set is considered indicative of strong content validity at the scale level, assuring that the instrument as a whole adequately captures the domain of safety factors relevant to irrigation construction in Nepal. Together, the reliability and content validity assessments ensure that the

data entering the PCA, AHP, and Monte Carlo Simulation stages are of sufficient quality to support the quantitative conclusions drawn from the analysis.

3.7 Research Matrix

The research matrix presented in Table 3 provides a structured overview of the alignment between the study's research questions, specific objectives, data sources, analytical methods, and expected outputs. It is intended to offer a clear, at-a-glance summary of how each element of the research design contributes to addressing the stated objectives and to demonstrate the logical coherence of the overall methodological framework.

Table 3: Research Matrix

Research Objective	Data Sources	Methods of Data Collection	Data Analysis Method	Expected Outcomes
To systematically identify, validate, and structure the key safety factors influencing irrigation construction projects.	Review of published research papers and reports, and a questionnaire survey	Primary- Expert review, and Questionnaire survey Secondary- Literature Review	Principal Component Analysis (PCA)	Validated and grouped safety factors
To quantify and prioritize the relative importance of the identified safety factors.	Questionnaire Survey	Primary- Questionnaire survey	Analytic Hierarchy Process (AHP)	Weighted ranking of safety factors
To probabilistically assess the overall safety level of irrigation construction projects under uncertainty.	Questionnaire Survey and weightage obtained from AHP	Primary- Questionnaire survey	Monte Carlo Simulation (MCS)	Safety Index distribution and safety level classification

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter presents and discusses the findings of the study in three sections, each corresponding directly to one of the three specific research objectives. Section 4.1 addresses the first objective, the systematic identification, validation, and structural analysis of safety factors, by reporting and interpreting the results of expert content validity assessment and principal component analysis. Section 4.2 addresses the second objective, the prioritization of validated safety factors by relative significance, by presenting and interpreting the AHP-derived global weights. Section 4.3 addresses the third objective, the probabilistic assessment of overall safety performance under uncertainty, by reporting and interpreting the Safety Index formulation and Monte Carlo Simulation results.

4.1 Identification, Validation, and Structural Analysis of Safety Factors

4.1.1 Expert Validation and Reliability Analysis

The 32 candidate safety factors identified from the literature review were subjected to expert content validity assessment. A panel of seven subject matter experts comprising experienced project managers, site engineers, and safety professionals with direct involvement in irrigation construction projects in Nepal independently rated the relevance of each factor using a four-point ordinal scale (1 = Not relevant; 4 = Highly relevant). Ratings of 3 or 4 were coded as indicating relevance, and the I-CVI for each factor was calculated as the proportion of experts assigning a relevant rating. An I-CVI threshold of 0.78 was applied for factor retention.

Of the 32 initially identified factors, 28 met or exceeded the 0.78 threshold and were retained for subsequent analysis. Four factors; Worker fatigue (I-CVI = 0.286), Substance use (I-CVI = 0.286), Communication barriers (I-CVI = 0.143), and Low worker morale (I-CVI = 0.714), did not achieve the required level of expert consensus and were excluded. The I-CVI values for all 32 factors are presented in Table 4. The Scale-Level CVI (S-CVI), calculated as the mean of all retained I-CVI values, was 0.954, confirming a high overall level of content validity across the retained factor set.

Table 4: CVI Results for All 32 Safety Factors

Safety Factor	Category	I-CVI	Decision
Insufficient safety training	Workers	1.000	Retained
Improper use of PPE	Workers	1.000	Retained
Unsafe worker behavior	Workers	0.857	Retained
*Worker fatigue**	Workers	0.286	Removed
*Substance use**	Workers	0.286	Removed
*Communication barriers**	Workers	0.143	Removed
Low worker morale	Workers	0.714	Removed
Absence of safety policies	Organizational	0.857	Retained
Low management commitment towards safety	Organizational	1.000	Retained
Poor reporting culture regarding accidents and near misses	Organizational	1.000	Retained
Insufficient safety budget	Organizational	0.857	Retained
Weak safety culture	Organizational	1.000	Retained
Poor documentation of accidents and near misses	Organizational	1.000	Retained
Weak site supervision	Managerial	1.000	Retained
Inadequate safety inspections	Managerial	1.000	Retained
Lack of safety officer	Managerial	1.000	Retained
Poor subcontractor management	Managerial	0.857	Retained
Inadequate work planning	Managerial	1.000	Retained
Lack of toolbox talks	Managerial	1.000	Retained
Lack of proper authorization before starting hazardous works	Managerial	1.000	Retained
Lack of clear safety instructions from supervisor to workers	Managerial	1.000	Retained
Improper equipment operation	Technical	1.000	Retained
Poor equipment maintenance	Technical	1.000	Retained
Unsafe scaffolding	Technical	1.000	Retained
Inadequate machine guarding	Technical	0.857	Retained
Material handling risks	Technical	1.000	Retained
Poor housekeeping	Site/Procedural	1.000	Retained
Unsafe site layout	Site/Procedural	0.857	Retained

Excavation hazards	Site/Procedural	0.857	Retained
Slippery or unstable surfaces	Site/Procedural	0.857	Retained
Poor emergency preparedness	Site/Procedural	1.000	Retained
Adverse weather exposure	Site/Procedural	0.857	Retained

The exclusion of the four factors with sub-threshold I-CVI values is substantively informative. Worker fatigue, substance use, and communication barriers, all commonly cited in the general construction safety literature, received notably low expert consensus ratings in the irrigation construction context. Expert commentary suggested that fatigue and substance use are relatively better controlled in the government-supervised, schedule-intensive irrigation project environment compared to informal urban construction, and that communication barriers were considered less salient given the predominantly Nepali-speaking workforce and close supervisory contact typical of smaller irrigation sites. This finding reinforces the importance of the CVI validation step: it demonstrates that safety factor sets developed for general construction cannot be imported without empirical verification of their contextual relevance.

Internal consistency of the survey data was assessed using Cronbach's Alpha. Both the importance ratings section and the frequency of occurrence section achieved values well above the 0.70 threshold, confirming excellent reliability of the instrument (Table 5). The alpha values of 0.963 and 0.973 indicate that respondents were highly consistent in their judgments across items within each section, providing strong assurance that the data entering the PCA and Monte Carlo Simulation stages are of sufficient quality.

Table 5: Cronbach's Alpha Reliability Statistics

Dataset	No. of Items	Cronbach's Alpha	Interpretation
Importance Ratings	28	0.963	Excellent
Frequency of Occurrence Ratings	28	0.973	Excellent

4.1.2 Identification of Major Components via Dimension Reduction Using Principal Component Analysis

In order to identify the major components, PCA was carried out. PCA was carried out using following steps.

Step a: KMO test to measure suitability of data for factor analysis

For assessment of the suitability of data for factors analysis, Kaiser-Meyer-Olkin (KMO) is used to measure the suitability of data for factor analysis. Similarly, Bartlett's test of Sphericity, correlation matrix, and determinant score are computed to detect the appropriateness of the data set for functioning factor analysis (Shrestha, 2021).The details are tabulated in table 6 below.

Table 6: KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.881
Bartlett's Test of Sphericity	Approx. Chi-Square	1565.667
	df	378
	Sig.	.000

To assess the suitability of the dataset for Principal Component Analysis (PCA), the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity were conducted, as is standard practice in factor analysis (Tabachnick & Fidell, 2013).The KMO test measures the proportion of variance among the forty six waste-related factors that may be attributed to common underlying factors, with values ≥ 0.6 indicating adequate suitability, ≥ 0.7 good, and ≥ 0.8 excellent(Kaiser, 1974). Bartlett's Test of Sphericity evaluates whether the correlation matrix of these factors is significantly different from an identity matrix, with a significant p-value ($p < 0.05$) confirming enough correlations for PCA(Bartlett, 1954). Additionally, the correlation matrix and determinant score were computed to verify the absence of multicollinearity or singularity, ensuring the dataset's appropriateness for factor analysis.

Applicability to the Current Study: The dataset, comprising 68 responses across 28 safety-related factors, was subjected to KMO and Bartlett's tests to confirm its suitability for PCA. These tests are not restricted to large datasets but are essential for any dataset undergoing factor analysis to validate the correlation (Hair et al., 2016). The KMO value of 0.881, reported in Table 3, exceeds the threshold of 0.8, indicating excellent sampling adequacy. Bartlett's Test of Sphericity was highly significant ($\chi^2 = 1565.667$, df =378, $p < 0.001$), confirming significant correlations among variables, making PCA appropriate for this dataset (Shrestha, 2021) (Kaiser, 1974).

Step b: Factor Extraction

In this study two techniques are used to assist in the decision concerning the number of factors to retain: Kaiser's Criterion (Eigen Value) and Scree Test. In this section, a result on the answer to the question, which is "identification of major components of safety factors in irrigation projects in Nepal" is discussed. For this purpose, the 28 factors were included in the PCA analysis. The eigenvalue technique was used to determine the number of factors to extract. In this case, only factors with eigenvalues of 1.0 or more were retained. Varimax was used for normalization to reduce the complexity of the factors to maximize the variance in the model.

In multivariate statistics, a scree plot is a line plot of the eigenvalues of factors or principal components in an analysis. The scree plot is used to determine the number of factors to retain in an exploratory factor analysis (EFA) or principal components to keep in a principal component analysis (PCA). As shown in Figure 2, scree plot describes that three latent variables have Eigen value >1.

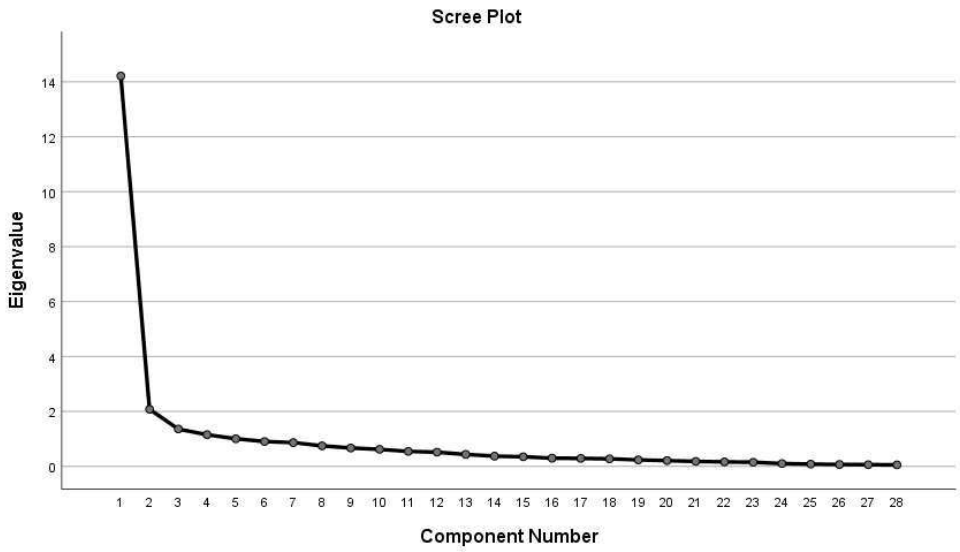

Figure 2: Scree Plot

In Figure 2, for a scree test, a graph is plotted with eigenvalues on the y-axis against the 28 component numbers in their order of extraction on the x-axis. The initial factors extracted are large factors with higher eigenvalues followed by smaller factors. The scree plot is used to determine the number of factors to retain. Here, the scree plot shows that there are 5 components for which the eigenvalue is greater than one and accounts for most of the total variability in data. The other component account for a very small proportion of the variability and are considered not so much important (Tabachnick & Fidell, 2013). The details are tabulated in table 7 below.

Table 7:Eigenvalues (EV) and Total Variance Explained Extraction Method: Principal Component Analysis

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	14.212	50.758	50.758	14.212	50.758	50.758	5.890	21.036	21.036
2	2.079	7.423	58.181	2.079	7.423	58.181	5.095	18.196	39.232
3	1.359	4.855	63.036	1.359	4.855	63.036	3.624	12.943	52.175
4	1.153	4.117	67.152	1.153	4.117	67.152	3.147	11.240	63.415
5	1.005	3.589	70.742	1.005	3.589	70.742	2.052	7.327	70.742
6	.905	3.234	73.975						

7	.865	3.091	77.066						
8	.748	2.671	79.738						
9	.669	2.390	82.127						
10	.619	2.212	84.340						
11	.545	1.947	86.287						
12	.517	1.846	88.133						
13	.435	1.553	89.686						
14	.372	1.330	91.015						
15	.350	1.249	92.264						
16	.298	1.064	93.328						
17	.289	1.033	94.361						
18	.274	.979	95.341						
19	.235	.840	96.181						
20	.209	.746	96.926						
21	.180	.643	97.569						
22	.162	.580	98.149						
23	.150	.535	98.684						
24	.102	.365	99.049						
25	.083	.296	99.345						
26	.068	.244	99.589						
27	.061	.218	99.807						
28	.054	.193	100.000						
Extraction Method: Principal Component Analysis.									

Table 7: demonstrates the eigenvalues and total variance explained. The extraction method of factor analysis used in this study is principal component analysis. Before extraction, 46 linear components are identified within the data set. After extraction and rotation, there are eleven distinct components within the data set for the eigenvalue > 1. The eleven factors are extracted accounting for a combined 70.742% of the total variance. It is suggested that the proportion of the total variance explained by the retained factors should be greater than 50%. The result shows that 70.742% of common variance shared by 5 components. This is the reflection of the KMO value, 0.881, which can be considered good and indicates that factor analysis is useful for the variables. This initial solution suggests that the final solution has extract not more than 5 components. In the scope of the study, it was determined that there are 5 components with an eigenvalue greater than 1. The factor analysis extracted 5 components with eigenvalues and corresponding variance explained as follows: Component 1 (Eigenvalue = 14.212, 50.752%), Component 2 (2.079, 7.423%), Component 3 (1.359, 4.855%), Component 4 (1.153, 4.117%), and Component 5 (1.005, 3.589%).

Step c: Factor Rotation and Interpretation

After avoiding the negative, cross-loadings and value lesser than 0.4 are tabulated in the rotated component matrix in Table 8 below:

A Principal Component Analysis (PCA) with Varimax rotation was conducted on 28 variables related to construction waste factors. The analysis resulted in the extraction of 5 distinct components, each clustering items that are conceptually related. The rotated component matrix helped identify underlying themes based on factor loadings. The extracted components are depicted in Table 4.5 along with the component themes and in table below.

Table 8: Rotated Component Matrix

Variable	Component 1	Component 2	Component 3	Component 4	Component 5
site_layout	.846				
scaffolding	.821				
equipment_use	.709				
maintenance	.707				
machine_guard	.678				
slippery	.676				
communication	.566				
excavation	.535				
emergency	.530				
work_planning		.793			
subcontractor		.759			
safety_budget		.677			
documentation		.670			
site_supervision		.607			
safety_officer		.577			
reporting_culture		.538			
weather		.517			
toolbox		.483			
safety_policy		.482			
management_commitment		.466			
safety_inspection			.777		
safety_culture			.679		
permit_work			.526		
ppe_use				.765	
unsafe_behavior				.752	
safety_training				.725	
housekeeping					.590
material_handling					.583

Weather was initially included in the principal component analysis but was subsequently excluded from the final solution due to ambiguous cross-loading and its negligible contribution to the internal consistency of Component 2.

Following principal component analysis with Varimax rotation, five components were extracted and interpreted based on variable loadings, including those below 0.5 to retain all available information. The loading of 5 components is tabulated in Table 9 below along with their reliability statistics.

Table 9: Five Components and Reliability Statistics

		Variables	Number of Items	Reliability Statistics	Interpretation
Components	**1**	communication, equipment_use, maintenance, scaffolding, machine_guard, site_layout, excavation, slippery, emergency	9	0.914	Excellent
	2	safety_policy, management_commitment, reporting_culture, safety_budget, documentation, site_supervision, safety_officer, subcontractor, work_planning, toolbox	10	0.901	Excellent
	3	safety_culture, safety_inspection, permit_work	3	0.717	Acceptable
	4	safety_training, ppe_use, unsafe_behavior	3	0.745	Acceptable
	5	material_handling, housekeeping	2	0.641* (Inter-item Correlation)	Good

**For Component 5 (2 items), inter-item correlation is reported.*

Reliability analysis was conducted to assess the internal consistency of the five components derived from principal component analysis. For Components 1 through 4, Cronbach's alpha coefficients were calculated. For Component 5, which contains only two items, the inter-item

correlation coefficient was used. Component 1 (Site Operations, Equipment & Environmental Safety) demonstrated excellent reliability with α = 0.914. Component 2 (Management Systems, Planning & Contractor Control) also showed excellent reliability with α = 0.902. Component 3 (Inspection, Permits & Safety Culture) achieved acceptable reliability with α = 0.717. Component 4 (Personal Behaviors, Training & PPE) achieved acceptable reliability with α = 0.745. For Component 5 (Housekeeping & Material Handling), the inter-item correlation was r = 0.641, indicating a good relationship between the two items. These results confirm that all five components possess satisfactory internal consistency for further analysis. After confirming with the reliability statistics, component naming was carried out. The details of component, its loading, naming of component and rationale behind is described in table 10 below.

Table 10: Rationale for Naming of Rotated Components

Proposed Component Name	Variables (Loading)	Rationale for Naming
Component 1: Site Operations, Equipment & Environmental Safety	site_layout (.846), scaffolding (.821), equipment_use (.709), maintenance (.707), machine_guard (.678), slippery (.676), communication (.566), excavation (.535), emergency (.530)	This component captures the physical and environmental dimensions of workplace safety. High loadings on site layout, scaffolding, equipment use, maintenance, machine guarding, slippery surfaces, excavation, and emergency preparedness indicate a focus on tangible hazards, infrastructure integrity, and operational conditions. Communication (.566) suggests that coordination is essential for safe site operations. This factor distinguishes environmental/equipment safety from administrative or behavioral measures.
Component 2: Management Systems, Planning & Contractor Control	work_planning (.793), subcontractor (.759), safety_budget (.677), documentation (.670), site_supervision (.607), safety_officer (.577), reporting_culture (.538), weather (.517), safety_policy (.482), toolbox (.483), management_commitment (.466)	This component reflects the administrative backbone of safety. High loadings on work planning, subcontractor management, budgeting, documentation, supervision, and safety officer presence indicate formalized organizational systems. Reporting culture (.538) suggests hazard reporting is managed at this level. Weather (.517) loads here, indicating that planning for environmental conditions is perceived as a managerial responsibility. Lower loadings on safety policy (.482), toolbox talks (.483), and management

		commitment (.466) still contribute to the theme of organizational control.
Component 3: Inspection, Permits & Safety Culture	safety_inspection (.777), safety_culture (.679), permit_work (.526)	This component combines formal verification processes with cultural elements. Safety inspection loads most strongly (.777), followed by safety culture (.679). Permit-to-work systems load moderately (.526), indicating that permit procedures are embedded within a broader cultural and auditing framework. The name reflects the integration of procedural (inspection/permit) and cultural (shared safety values) dimensions.
Component 4: Personal Behaviors, Training & PPE	ppe_use (.765), unsafe_behavior (.752), safety_training (.725)	This component is defined by individual-level actions. High and nearly equal loadings on PPE use, safety training, and unsafe behavior indicate that these three behavioral aspects strongly co-occur. Where training is effective, PPE compliance follows, and unsafe behaviors decrease. This component captures frontline behavioral performance distinct from environmental (Component 1), managerial (Component 2), or inspection/culture (Component 3) factors.
Component 5: Housekeeping & Material Handling	housekeeping (.590), material_handling (.583)	This two-variable component captures foundational workplace organization. Housekeeping refers to orderliness, cleanliness, and clear walkways. Material handling involves safe lifting, moving, stacking, and storage of materials. Their joint loading (.590 and .583) indicates that good housekeeping practices coexist with proper material handling. Although this component explains less variance, its practical significance is high, as poor housekeeping and improper material handling are leading causes of slips, trips, falls, and musculoskeletal injuries.

Discussions of Components:

Component 1: Site Operations, Equipment & Environmental Safety

This component encompasses the physical and environmental dimensions of workplace safety. The highest loadings are observed for site layout (.846), scaffolding (.821), equipment use

(.709), maintenance (.707), machine guarding (.678), slippery surfaces (.676), excavation (.535), and emergency preparedness (.530). Communication loads at .566, indicating that safe site operations require coordination among workers. Organizations scoring high on this component prioritize safe physical infrastructure, proper equipment handling, preventive maintenance, hazard control (slippery surfaces, excavation risks), and emergency response readiness. This factor captures the tangible, on-the-ground reality of workplace safety, distinguishing it from administrative or behavioral measures.

Component 2: Management Systems, Planning & Contractor Control

This component captures the administrative and managerial backbone of safety performance. The highest loadings are observed for work planning (.793), subcontractor management (.759), safety budget (.677), documentation (.670), site supervision (.607), safety officer presence (.577), and reporting culture (.538). Lower but meaningful loadings include safety policy (.482), toolbox talks (.483), and management commitment (.466). This component distinguishes organizations that have formalized safety systems budgets, written policies, supervisory oversight, subcontractor controls, and hazard reporting mechanisms from those that rely on informal or reactive approaches. A high score reflects strong institutionalization of safety through planning, resource allocation, documentation, and accountability structures that extend to subcontractors.

Component 3: Inspection, Permits & Safety Culture

Component 3 brings together formal verification processes with cultural elements. Safety inspection loads most strongly (.777), followed by safety culture (.679). Permit-to-work systems load at .526, indicating that permit procedures are an important but less dominant element of this factor. This combination suggests that organizations scoring high on this component do not merely conduct inspections and issue permits mechanistically; rather, these activities are reinforced by a supportive safety culture that values compliance, thoroughness, and shared responsibility for high-risk tasks. The factor captures the integration of procedural (inspection and permit) and cultural (shared safety values) dimensions.

Component 4: Personal Behaviors, Training & PPE

This component is defined by three strongly loading variables: PPE use (.765), unsafe behavior (.752), and safety training (.725). Unlike earlier components that emphasize environment, management, or inspection systems, Component 4 focuses squarely on the individual worker. The nearly equal and substantial loadings suggest that these three behavioral aspects co-occur: where training is effective, PPE compliance follows, and unsafe behaviors decrease. A high score on this component reflects workers who are adequately trained, use personal protective equipment consistently, and refrain from unsafe acts such as taking shortcuts or violating procedures. This component is particularly valuable for diagnosing frontline safety performance distinct from managerial or infrastructural factors.

Component 5: Housekeeping & Material Handling

Component 5 is the smallest and most focused factor, comprising housekeeping (.590) and material handling (.583). Housekeeping refers to the orderly arrangement of workspaces, removal of debris, and clear walkways, while material handling involves the safe lifting, moving, stacking, and storage of materials. Their joint loading indicates that workplaces with good housekeeping also tend to practice safe material handling, and vice versa. Although this component explains less variance than others, its practical significance is high: poor housekeeping and improper material handling are leading causes of slips, trips, falls, and musculoskeletal injuries. A high score on this component reflects foundational workplace organization that prevents routine but frequent incidents.

4.2 Prioritization of Safety Factors

The second objective of the study was to prioritize the safety factors of five PCA-derived components and its factors loading. The Analytic Hierarchy Process was applied across a two-level hierarchy: among the five PCA-derived components, and among individual factors within each component. All pairwise comparison matrices achieved Consistency Ratio values below the 0.10 threshold, confirming the logical coherence of the expert judgments. The final global priority weights and local weights for all 27 validated factors, ranked in descending order of importance, are presented in Table 11.

Table 11: AHP Global and Local Priority Weights for Validated Safety Factors (Ranked)

Rank	Safety Factor	Global Weight	Local Weight
1	Insufficient safety budget	0.1050	0.2834
2	Lack of clear safety instructions from supervisor to workers	0.0793	0.2379
3	Insufficient safety training	0.0644	0.5792
4	Poor emergency preparedness	0.0603	0.1810
5	Material handling risks	0.0567	0.7652
6	Absence of safety policies	0.0508	0.1371
7	Inadequate work planning	0.0468	0.1262
8	Excavation hazards	0.0463	0.1388
9	Low management commitment towards safety	0.0459	0.1239
10	Inadequate safety inspections	0.0395	0.3559
11	Weak safety culture	0.0395	0.3551
12	Lack of safety officer	0.0376	0.1014
13	Unsafe site layout	0.0363	0.1088
14	Slippery or unstable surfaces	0.0352	0.1055
15	Lack of proper authorization before starting hazardous works	0.0321	0.2890
16	Improper equipment operation	0.0294	0.0883
17	Poor reporting culture regarding accidents and near misses	0.0290	0.0783
18	Unsafe worker behavior	0.0257	0.2313
19	Poor equipment maintenance	0.0220	0.0661
20	Improper use of PPE	0.0211	0.1895
21	Poor housekeeping	0.0174	0.2348
22	Weak site supervision	0.0159	0.0429
23	Lack of toolbox talks	0.0139	0.0376
24	Poor subcontractor management	0.0134	0.0362
25	Unsafe scaffolding	0.0133	0.0400
26	Poor documentation of accidents and near misses	0.0122	0.0330
27	Inadequate machine guarding	0.0112	0.0336

The consistency ratios for all pairwise comparison matrices ranged from 0.000 to 0.099, all below the acceptable threshold of 0.10 as shown in Table 12 This confirms that the expert judgments were consistent and the derived weights are reliable for interpretation and decision-making (Saaty, 1980)

Table 12: Consistency ratio of sub-factors

Matrix	CR Value	Judgment
Main criteria (safety factor categories)		
Sub-factors under Management Systems	0.019239708	Max, 1
Sub-factors under Site Operations	0.01175918	2
Sub-factors under Training & Behavior	0.00573486	4
Sub-factors under Inspection & Culture	0.009354666	3
Sub-factors under Housekeeping	0	Min
Overall hierarchy		

Insufficient safety budget (w = 0.1050) emerges as the single most influential safety factor by a considerable margin. In the Nepalese irrigation construction context, financial constraint occupies a structurally different position from all other safety factors: it is not merely one risk driver among many but a prerequisite constraint that simultaneously limits the capacity to address every other safety management dimension. Adequate safety budgets fund the appointment of dedicated safety officers, the provision of protective equipment, the delivery of training programs, and the establishment of emergency response systems. When the budget is insufficient, every downstream safety management function is constrained simultaneously, producing a compounding effect that no organizational or behavioral intervention can fully compensate for. This finding aligns with Awwad et al. (2016), who identified budget inadequacy as among the most consequential organizational barriers to safety performance in developing country construction, and reinforces the case for treating safety expenditure as a non-negotiable contract provision rather than a discretionary project cost.

Lack of clear safety instructions from supervisors to workers (w = 0.0793) and insufficient safety training (w = 0.0644) ranked second and third, jointly highlighting the critical role of information transfer in preventing accidents. In the irrigation construction setting, where tasks such as deep excavation, canal lining in confined spaces, and work near open watercourses carry hazards that are not intuitively apparent to workers without domain-specific knowledge, the consequences of communication and training deficiencies are particularly severe. Workers who do not receive task-specific pre-work safety briefings or adequate hazard recognition training are exposed to preventable risks not because protective measures are unavailable but because they lack the knowledge to apply them. Sawacha et al. (1999) identified communication deficiencies as a fundamental contributor to construction accidents, and Durdyev et al. (2017) found inadequate training to be a consistently leading performance driver across developing country construction contexts.

Poor emergency preparedness (w = 0.0603) and material handling risks (w = 0.0567) complete the top five. The high rank of emergency preparedness reflects the geographic reality of irrigation construction in Nepal: many project sites are located in remote valleys and hillside locations where emergency services are hours away, and the absence of site-specific emergency response plans, covering trench collapse, equipment incidents, and drowning in canal structures, can convert survivable incidents into fatalities. Material handling risks rank fifth, reflecting the physically intensive nature of irrigation construction, where manual and semi-mechanized handling of pipes, precast canal sections, and heavy earthmoving creates persistent exposure to struck-by, caught-in-between, and musculoskeletal injury hazards. Together, the top ten factors account for approximately 56% of the total priority weight across all 27 factors, confirming that a targeted and concentrated set of safety management improvements, focused principally on financial adequacy, communication quality, training provision, emergency preparedness, and material handling practices, would address the dominant share of safety risk in irrigation construction.

4.2.1 Mapping of AHP Risk Factors to PCA Components

Having established the ranked priority of individual safety risk factors through AHP, this section integrates these findings with the PCA component structure derived from the survey data in Objective 1. The purpose of this integration is twofold. First, it identifies which

of the five empirically derived PCA components contain the highest concentration of expert-weighted risks, thereby revealing whether the latent factor structure observed in worker survey responses aligns with expert risk prioritization. Second, it enables triangulation between the two methods: PCA captures what varies across workers' perceptions of safety practices, while AHP captures what experts judge as most consequential for safety outcomes. Table 13 maps all 27 AHP-ranked risk factors onto the five PCA components: Component 2 (Management Systems, Planning & Contractor Control) receives 10 factors, Component 1 (Site Operations, Equipment & Environmental Safety) receives 9 factors, Component 3 (Inspection, Permits & Safety Culture) and Component 4 (Personal Behaviors, Training & PPE) each receive 3 factors, and Component 5 (Housekeeping & Material Handling) receives 2 factors.

Table 13: Mapping of AHP Risk Factors to PCA Components

Rank	Safety Factor	Global Weight	PCA Component
1	Insufficient safety budget	0.1050	Component 2 (Management Systems)
2	Lack of clear instructions from supervisor to workers	0.0793	Component 1 (Site Operations)
3	Insufficient safety training	0.0644	Component 4 (Training & Behavior)
4	Poor emergency preparedness	0.0603	Component 1 (Site Operations)
5	Material handling risks	0.0567	Component 5 (Housekeeping)
6	Absence of safety policies	0.0508	Component 2 (Management Systems)
7	Inadequate work planning	0.0468	Component 2 (Management Systems)
8	Excavation hazards	0.0463	Component 1 (Site Operations)
9	Low management commitment towards safety	0.0459	Component 2 (Management Systems)

10	Inadequate safety inspections	0.0395	Component 3 (Inspection & Culture)
11	Weak safety culture	0.0395	Component 3 (Inspection & Culture)
12	Lack of safety officer	0.0376	Component 2 (Management Systems)
13	Unsafe site layout	0.0363	Component 1 (Site Operations)
14	Slippery or unstable surfaces	0.0352	Component 1 (Site Operations)
15	Lack of proper authorization before starting hazardous works	0.0321	Component 3 (Inspection & Culture)
16	Improper equipment operation	0.0294	Component 1 (Site Operations)
17	Poor reporting culture regarding accidents and near misses	0.0290	Component 2 (Management Systems)
18	Unsafe worker behavior	0.0257	Component 4 (Training & Behavior)
19	Poor equipment maintenance	0.0220	Component 1 (Site Operations)
20	Improper use of PPE	0.0211	Component 4 (Training & Behavior)
21	Poor housekeeping	0.0174	Component 5 (Housekeeping)
22	Weak site supervision	0.0159	Component 2 (Management Systems)
23	Lack of toolbox talks	0.0139	Component 2 (Management Systems)
24	Poor subcontractor management	0.0134	Component 2 (Management Systems)
25	Unsafe scaffolding	0.0133	Component 1 (Site Operations)
26	Poor documentation of accidents and near misses	0.0122	Component 2 (Management Systems)

27	Inadequate machine guarding	0.0112	Component 1 (Site Operations)

Discussion:

Table 13 maps each of the 27 AHP-ranked safety risk factors onto the five PCA components derived from the survey data in Objective 1. This integration serves two purposes: first, it identifies which PCA components contain the highest concentration of expert-weighted risks; second, it enables triangulation between what workers reported (through PCA factor loadings) and what experts prioritized (through AHP pairwise comparisons).

Component 2 (Management Systems, Planning & Contractor Control) contains the largest number of mapped risk factors (10 out of 27) and, more importantly, includes the highest-ranked factor overall insufficient safety budget (rank 1, w = 0.1050). This component also contains ranks 6, 7, 9, 12, 17, 22, 23, 24, and 26, demonstrating that experts consistently identified managerial and administrative failures as the most consequential risk category. The concentration of top-ranked risks within Component 2 validates the PCA finding that management systems constitute the foundational dimension of safety performance. In practical terms, interventions targeting budget adequacy, safety policies, work planning, management commitment, safety officer presence, reporting culture, supervision, toolbox talks, subcontractor management, and documentation would address the majority of high-priority risks identified by experts.

Component 1 (Site Operations, Equipment & Environmental Safety) contains nine risk factors, including lack of clear instructions from supervisor to workers (rank 2, w = 0.0793), poor emergency preparedness (rank 4, w = 0.0603), excavation hazards (rank 8, w = 0.0463), unsafe site layout (rank 13), slippery or unstable surfaces (rank 14), improper equipment operation (rank 16), poor equipment maintenance (rank 19), unsafe scaffolding (rank 25), and inadequate machine guarding (rank 27). Notably, the second-highest ranked factor overall lack of clear instructions maps to Component 1, not Component 2. This is conceptually significant: communication between supervisors and workers is placed within site operations rather than management systems, suggesting that experts perceive instruction delivery as an on-site operational activity rather than an administrative function. The collective global weight of

Component 1 (0.3333) is nearly equivalent to that of Component 2 (0.3705), indicating that site operations and management systems are both critically important and closely interrelated.

Component 3 (Inspection, Permits & Safety Culture) contains three risk factors: inadequate safety inspections (rank 10, w = 0.0395), weak safety culture (rank 11, w = 0.0395), and lack of proper authorization (rank 15, w = 0.0321). The nearly identical weights for inspections and safety culture (0.0395 each) suggest that experts view these as equally important within this component. The mapping confirms that inspection systems and permit-to-work procedures are conceptually linked to safety culture, as originally indicated by the PCA loading structure.

Component 4 (Personal Behaviors, Training & PPE) contains three risk factors: insufficient safety training (rank 3, w = 0.0644), unsafe worker behavior (rank 18, w = 0.0257), and improper PPE use (rank 20, w = 0.0211). The high rank of insufficient safety training (third overall) is notable: it is the only behavioral or training factor to appear in the top five, reinforcing the earlier discussion that training deficiencies are a critical information-transfer failure. The lower ranks of unsafe behavior and improper PPE use suggest that experts view these as downstream consequences of inadequate training and management systems rather than primary causes.

Component 5 (Housekeeping & Material Handling) contains two risk factors: material handling risks (rank 5, w = 0.0567) and poor housekeeping (rank 21, w = 0.0174). Material handling ranks fifth overall despite Component 5 containing the fewest factors and the smallest total weight. This divergence indicates that while housekeeping and material handling may not vary substantially across survey respondents, experts perceive material handling as a high-consequence risk in irrigation construction, where manual movement of pipes, precast sections, and earthmoving materials creates frequent exposure to struck-by and musculoskeletal injury hazards.

4.2.2 Triangulation Between PCA and AHP

Having established the distribution of AHP weights across components, this section now integrates these findings with the PCA variance explained from Objective 1. Table 14 presents the triangulation between the two methods, comparing PCA variance (what varies across workers' perceptions) with AHP sum weights (what experts judge as consequential).

Table 14: Triangulation of PCA and AHP Findings

PCA Component	Name	PCA Variance (%)	PCA Rank	AHP Sum Weight	AHP Rank	Triangulation
Component 1	Site Operations, Equipment & Environmental Safety	21.036%	1st	0.3333	2nd	Divergence (PCA higher)
Component 2	Management Systems, Planning & Contractor Control	18.196%	2nd	0.3705	1st	Divergence (AHP higher)
Component 3	Inspection, Permits & Safety Culture	12.943%	3rd	0.1111	4th	Partial divergence
Component 4	Personal Behaviors, Training & PPE	11.240%	4th	0.1112	3rd	Partial divergence
Component 5	Housekeeping & Material Handling	7.327%	5th	0.0741	5th	Convergence

Discussion:

Convergence: Component 5 (Housekeeping & Material Handling)

Perfect convergence is observed for Component 5. Both methods rank this component lowest: PCA explains only 7.327% of variance (5th rank), and AHP assigns the smallest total weight

of 0.0741 (5th rank). This consistent low ranking indicates that housekeeping and material handling, while not unimportant, are consistently perceived as less critical than the other four dimensions by both workers and experts.

Safety interventions should prioritize Component 5 last. However, within this component, material handling risks individually rank 5th in AHP (w = 0.0567), suggesting that material handling specifically requires attention before general housekeeping. Investments in mechanical lifting aids, ergonomic training, and safe material movement procedures will yield higher returns than generalized housekeeping campaigns.

Partial Divergence: Components 3 and 4 (Inspection & Culture vs. Training & Behavior)

For Components 3 and 4, the ranks are reversed between methods, though the differences are minimal. PCA ranks Component 3 (Inspection, Permits & Safety Culture) higher (12.943%, 3rd rank) than Component 4 (Training & Behavior) (11.240%, 4th rank). AHP reverses this order: Component 4 (Training & Behavior) ranks 3rd (0.1112) and Component 3 ranks 4th (0.1111). The near-equivalence of the AHP weights (0.1112 vs 0.1111) and the close PCA percentages (12.94% vs 11.24%) suggest that these two dimensions are statistically and practically similar in importance.

The slight reversal likely reflects methodological differences rather than substantive disagreement. PCA captures what varies across workers' experiences: inspection systems and safety culture may show more site-to-site variation than training and behavior. AHP captures what experts judge as consequential: training deficiencies (ranked 3rd overall) may be perceived as having higher consequence severity than inspection failures (ranked 10th overall). The near-equivalence indicates that both dimensions are of secondary importance after management systems and site operations.

Organizations should address inspection systems, safety culture, training, and behavior as an integrated package rather than treating them as separate priorities. Improving training effectiveness will likely improve safety behavior and PPE compliance; strengthening inspection systems will likely reinforce safety culture. Neither dimension should be neglected, but neither requires priority over management systems or site operations.

Major Divergence: Components 1 and 2 (Site Operations vs. Management Systems)

The most significant divergence occurs for the top two components. PCA ranks Component 1 (Site Operations) highest, explaining 21.036% of variance. AHP ranks Component 2 (Management Systems) highest, with 0.3705 (37.05%) of total weight. Component 1 ranks second in AHP (0.3333, 33.33%), and Component 2 ranks second in PCA (18.196%).

Interpretation of Divergence: This divergence is methodologically meaningful and theoretically important. It indicates that:

- **From (PCA):** Site operations including site layout, scaffolding, equipment uses and maintenance, machine guarding, slippery surfaces, communication, excavation safety, and emergency preparedness show the greatest variation across different irrigation construction sites. Workers perceive these physical and operational conditions as the dimensions where safety practices differ most dramatically from one project to another.
- **From experts' perspective (AHP):** Management systems including safety budget, work planning, safety policies, management commitment, safety officer presence, reporting culture, supervision, toolbox talks, subcontractor management, and documentation carry the highest consequence weight. Experts judge that when these administrative and organizational systems fail, the downstream effects on all other safety dimensions are more severe and harder to compensate for.

The divergence is not a contradiction but a complement. Workers notice and report variation in physical site conditions because these are immediately visible and directly affect their daily work. Experts, taking a systems-level view, recognize that management systems are antecedent conditions that determine the quality of site operations. A project with strong management systems is more likely to maintain safe site layouts, properly guard machines, maintain equipment, and prepare for emergencies. Conversely, even a well-designed site can become unsafe if management systems fail to provide adequate budget, planning, or supervision.

The divergence suggests a two-pronged strategy. In the short term, direct improvements to site operations better site layouts, proper machine guarding, regular equipment maintenance, and emergency preparedness can yield immediate risk reduction that workers will readily perceive.

In the long term, strengthening management systems ensuring adequate safety budgets, mandating formal work planning, establishing clear safety policies, and holding management accountable is essential for sustaining those improvements across multiple projects. Experts are correct that management systems are foundational, but workers are also correct that site operations show the most immediate and visible variation. Effective safety improvement requires addressing both.

4.3 Probabilistic Safety Performance Assessment

The third objective of the study was assessing the probabilistic safety performance. For this safety index and Montecarlo simulations was carried out.

4.3.1 Safety Index and Monte Carlo Simulation Results

The composite Safety Index was computed by integrating the AHP-derived global weights (w_i) with normalized factor occurrence frequency values (f_i) from the survey data, where f_i represents the mean occurrence frequency of each safety factor scaled from 0 to 1. The deterministic Safety Index, calculated from mean occurrence frequencies, was:

$$\mathbf{SI\ (deterministic) = \Sigma\ (w_i \times f_i) = 0.512}$$

A value of 0.512 places overall safety performance within the Moderate safety level ($0.4 \leq SI \leq 0.7$), indicating a meaningful combined burden of safety risk factors that warrants sustained management attention. The safety level thresholds (Unsafe: $SI < 0.40$, Moderate: $0.40 \leq SI \leq 0.70$, Safe: $SI > 0.70$) were established with reference to established risk classification frameworks in construction safety literature. (Li & Wang, 2021) classified risk levels for engineering construction, defining the 0.4–0.6 range as "relatively high risk" requiring preventive measures, while an (NIH, 2023) defined the 0.4–0.6 range as "Safer" with the recommended action of strengthening prevention and monitoring. The upper bound of 0.70 for the Moderate category aligns with the Level 2 threshold (0.6–0.8 = "very high risk") in (Li & Wang, 2021), beyond which risk requires more aggressive intervention

To incorporate the uncertainty inherent in the variability of safety factor occurrence across different projects and site conditions, a Monte Carlo simulation was performed over

10,000 iterations, sampling each factor's occurrence frequency from a triangular distribution parameterized by the minimum, mode, and maximum observed survey responses. The summary statistics of the simulated Safety Index distribution are presented in Table 15.

Table 15: Summary Statistics of Simulated Safety Index Distribution (n = 10,000 iterations)

Statistic	Value
Mean Safety Index	0.512
Median Safety Index	0.512
Standard Deviation	0.045
90% Confidence Interval	[0.438, 0.587]

The near-identical mean and median (both 0.512) confirm that the simulated distribution is approximately symmetric, consistent with the Central Limit Theorem's prediction for the weighted sum of independent triangular distributions. The standard deviation of 0.045 (coefficient of variation ≈ 8.8%) represents moderate but practically meaningful uncertainty. The 90% confidence interval [0.438, 0.587] spans 0.149 Safety Index units, meaning that under realistic variability in safety factor occurrence across different project teams and site conditions, overall safety performance could range from a worst-case 5th percentile of 0.438 to a best-case 95th percentile of 0.587. The full probability distribution of simulated Safety Index values is illustrated in Figure 4.2

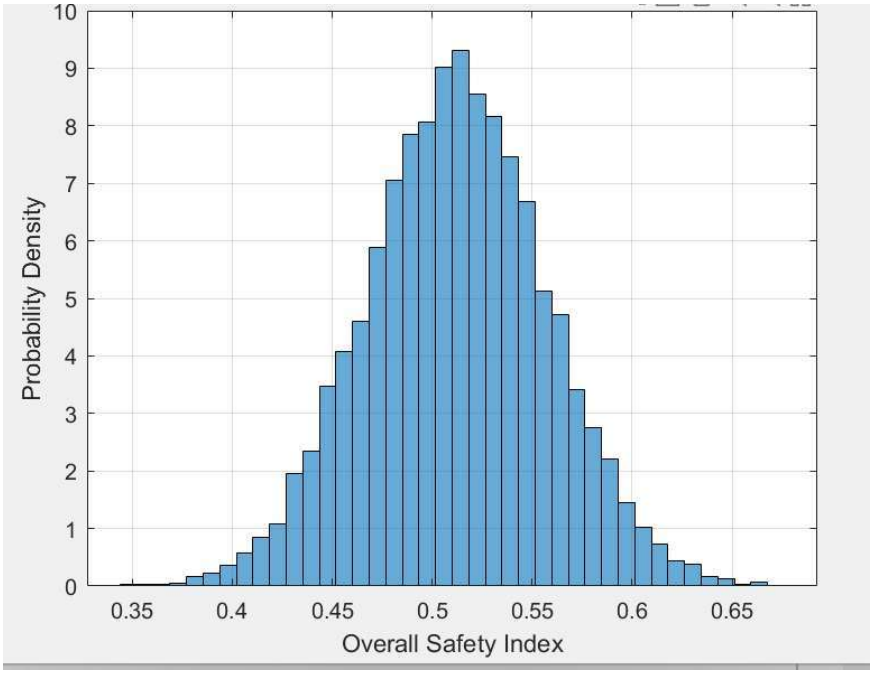

Figure 3: Probability Density Distribution of Simulated Safety Index Values (Monte Carlo Simulation, n = 10,000 iterations)

The histogram confirms the approximate normality of the output distribution, with a clear unimodal peak centred near 0.51 and a slight rightward tail, reflecting a marginally greater probability of adverse deviations from the central estimate than of favorable ones, a pattern consistent with the asymmetric nature of the triangular distributions used as inputs for factors with higher-end frequency ratings.

4.3.2 Safety Level Classification and Discussion

Each of the 10,000 simulated Safety Index values was classified against the three-tier framework established in Section 3.8. The resulting probability estimates for each safety level are presented in Table 16.

Table 16: Safety Level Classification Probabilities from Monte Carlo Simulation

Safety Level	SI Threshold	Probability (%)	Interpretation
Unsafe	SI < 0.40	0.67%	Rare but non-negligible; occurs under worst-case combinations of high-frequency risk factors.

Moderate	$0.40 \leq SI \leq 0.70$	99.33%	Dominant regime; moderate persistent risk burden requiring targeted and sustained intervention
Safe	$SI > 0.70$	0.00%	Not achieved under current safety factor occurrence patterns; substantial systemic improvement required

The classification results establish with high probabilistic confidence that irrigation construction projects in Nepal operate within a state of persistent moderate safety risk. The 99.33% probability of Moderate classification is not a neutral finding. It reflects a construction environment in which basic safety measures are partially in place but are insufficiently resourced, inconsistently implemented, and inadequately monitored a pattern that Durdyev et al. (2017) and Awwad et al. (2016) described as characteristic of developing country construction sectors where rudimentary safety provisions coexist with significant enforcement and resource gaps. The Nepalese irrigation construction sector fits this characterization closely, and the quantitative framing of this pattern as a 99.33% probability (rather than a qualitative observation) substantially strengthens the evidential basis for policy action.

Integration with PCA components: The Safety Index implicitly incorporates the PCA-derived component structure because the AHP weights used in the calculation were mapped onto the five components (Table 2). Thus, the Moderate safety level reflects the combined influence of all five dimensions, with Component 2 (Management Systems) contributing the largest share (37.05% of total weight), followed by Component 1 (Site Operations) at 33.33%.

The complete absence of Safe outcomes across all 10,000 simulation iterations is perhaps the most practically significant finding of the entire analysis. Under no plausible combination of safety factor occurrence rates drawn from the observed survey response distributions does overall safety performance approach the low-risk threshold. This is not a statistical artifact but a reflection of the genuine weight of safety risk factors in current irrigation construction practice: even in the most favorable scenarios sampled by the simulation, the aggregated burden of organizational deficiencies, site hazards, and worker-level risks remains above the threshold that would characterize genuinely well-managed construction safety. Achieving Safe classification, a meaningful and realistic safety goal would

require not marginal improvements to individual factors but fundamental shifts across multiple safety dimensions simultaneously, particularly in safety budget adequacy, the quality and consistency of supervisor-to-worker communication, training provision tailored to irrigation-specific hazards, and site-level hazard control.

The value of the probabilistic approach becomes most apparent when comparing the deterministic estimate (SI = 0.512) with the full simulated distribution. A planner relying solely on the point estimate would design safety interventions calibrated to a single expected scenario. In contrast, the simulation reveals that there is a non-trivial 0.67% probability of Unsafe conditions (approximately 1 in every 150 simulated project scenarios), and that the worst-case 5th percentile scenario (SI = 0.438) already implies conditions meaningfully more hazardous than the expected value. In environments where the consequences of safety failures include fatalities and serious injuries, a 1-in-150 probability of severely adverse conditions is not negligible: it warrants the deployment of additional protective measures, the strengthening of emergency preparedness systems, and the establishment of safety monitoring protocols capable of detecting adverse deviations from expected safety conditions before they escalate. Tixier et al. (2017) demonstrated that deterministic safety models systematically underestimate adverse outcome frequencies by ignoring input variability; the present study operationalizes this insight within a multi-factor framework specifically adapted to the data-limited context of irrigation construction in Nepal.

Taken together, the findings of Sections 4.1, 4.2, and 4.3 converge on a coherent and practically actionable picture of safety risk in Nepalese irrigation construction. Safety factors are organized around a dominant organizational and management dimension, with financial constraint at its apex. The overall safety burden is moderate but persistent, and no safe outcome is achievable under current conditions without systemic, multi-dimensional improvement. Project managers, contractors, and government project owners should prioritize safety budget adequacy as the foundational prerequisite, structured communication and training systems as the primary competency-building interventions, and probabilistic monitoring of the Safety Index as a routine tool for benchmarking progress toward the Safe performance threshold.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study developed and applied an integrated five-stage probabilistic framework for assessing safety performance in irrigation construction projects in Nepal. The conclusions are organized according to the three specific objectives of the research.

Identification, Validation, and Structuring of Safety Factors

Expert validation using the Content Validity Index (CVI) confirmed 28 of 32 candidate safety factors as relevant to the irrigation construction context, with a scale-level CVI of 0.954 indicating strong inter-expert agreement. Four factors worker fatigue, substance use, communication barriers, and low worker morale were excluded, demonstrating that general construction safety factor sets require contextual validation.

Principal Component Analysis (PCA), supported by a KMO value of 0.881 and a significant Bartlett's test ($p < 0.001$), identified five underlying safety dimensions collectively explaining 70.74% of total variance. These were: Site Operations, Equipment & Environmental Safety (21.04%); Management Systems, Planning & Contractor Control (18.20%); Inspection, Permits & Safety Culture (12.94%); Personal Behaviors, Training & PPE (11.24%); and Housekeeping & Material Handling (7.33%). All five components demonstrated acceptable to excellent reliability (α ranging from 0.717 to 0.914).

The dominance of Site Operations and Management Systems together explaining nearly 40% of total variance establishes that the physical-operational and organizational-managerial layers of safety management are the most pervasive determinants of safety performance in irrigation construction.

Prioritization of Safety Factors

The Analytic Hierarchy Process (AHP) produced consistent global priority weights, with all pairwise comparison matrices achieving Consistency Ratio values below the 0.10 threshold. The top ten factors accounted for approximately 56% of total priority weight.

Insufficient safety budget (w = 0.1050) emerged as the single most influential safety factor, not merely a risk driver but a prerequisite constraint that simultaneously limits capacity to address all other safety dimensions. Lack of clear safety instructions from supervisors to workers (w = 0.0793) and insufficient safety training (w = 0.0644) ranked second and third, highlighting information transfer and competency development as critical intervention points. Poor emergency preparedness (w = 0.0603) and material handling risks (w = 0.0567) completed the top five.

Probabilistic Safety Performance Assessment

The deterministic Safety Index was 0.512, placing overall safety performance within the Moderate level ($0.4 \leq SI \leq 0.7$). Monte Carlo Simulation over 10,000 iterations, incorporating triangular distributions parameterized by survey response ranges, produced a mean Safety Index of 0.512 (SD = 0.045) with a 90% confidence interval of [0.438, 0.587].

Probabilistic safety level classification revealed that 99.33% of simulated outcomes fell within the Moderate category, 0.67% within Unsafe, and no simulation reached the Safe threshold. This complete absence of Safe outcomes is the most practically significant finding: under no plausible combination of safety factor occurrence rates does overall safety performance approach the low-risk threshold.

Triangulation between PCA and AHP revealed convergence on Component 5 (Housekeeping) as lowest priority and divergence on the top two components: PCA ranked Site Operations highest (reflecting where workers perceive greatest variation), while AHP ranked Management Systems highest (reflecting where experts judge greatest consequence). This divergence is not a contradiction but a complement, indicating that effective safety improvement requires both short-term operational improvements and long-term systemic strengthening.

5.2 Recommendations from the Study

Project-Level Recommendations

i. Ensure adequate safety budget allocation as a mandatory baseline, treating safety expenditure as a non-negotiable contract provision. Prepare explicit safety cost plans before project commencement and formally report any shortfalls to project owners.

ii. Safety Communication and Training

iii. Institutionalize daily safety communication through standardized pre-task briefings in workers' native language and regular toolbox talks.

iv. Implement context-specific safety training focused on excavation risks, water exposure, slope instability, confined spaces, and emergency response, with practical competency checks.

v. Emergency Preparedness and Site Operations

vi. Develop and regularly test site-specific emergency response plans covering trench collapse, equipment incidents, drowning, and medical evacuation, with drills conducted at least quarterly.

vii. Prioritize material handling safety by providing mechanical lifting aids, conducting ergonomic training, and implementing safe lifting policies.

Organizational-Level Recommendations

i. Adopt comprehensive safety management systems that explicitly address all five PCA-derived components, recognizing that management systems carry the highest consequence weight.

ii. Include safety capacity (budget adequacy, safety officer qualifications, training quality) as a weighted criterion in contractor selection and performance evaluation.

iii. Establish structured, confidential reporting systems for accidents, near-misses, and safety concerns, with documentation maintained for trend analysis.

Policy-Level Recommendations

i. Develop sector-specific safety regulations for irrigation construction aligned with ILO Convention No. 167, addressing excavation in unstable terrain, water-related hazards, and remote site operations.

ii. Mandate minimum safety budget thresholds for government-funded irrigation projects above defined scales, making these provisions contractually enforceable.

iii. Require certified safety officers on all irrigation construction projects above a defined scale.

iv. Establish a national construction accident reporting system to enable benchmarking and evidence-based safety management.

5.3 Recommendations for Further Study

i. Cross-sectoral application. Apply the integrated framework to other infrastructure sectors (rural roads, hydropower, water supply) to assess transferability and identify sector-specific variations.

ii. Sample expansion. Increase sample size to enable advanced statistical methods including Confirmatory Factor Analysis and Structural Equation Modeling.

iii. Empirical calibration. Replace triangular distributions with empirically derived probability distributions as safety data become available.

iv. Economic analysis. Evaluate cost-effectiveness of safety interventions through cost-benefit analysis and return on safety investment calculations.

v. Longitudinal monitoring. Apply the framework longitudinally to track safety performance over time and evaluate intervention effectiveness.

vi. Leading indicator integration. Integrate findings with leading indicator frameworks to develop predictive safety models.

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Annexes

Annex 1: MATLAB Code for Monte Carlo Simulation

```
clc;
clear;

%% ================== INPUT SECTION ==================

% Number of Monte Carlo simulations
numSim = 10000;

% Number of safety factors
N = 28;

% ---------------------------------------------------
% Normalized factor weights (1 × N)
% Replace with your actual RII-based weights
% ---------------------------------------------------
weights = [ ...
    0.037 0.036 0.037 0.036 0.037 0.035 0.037 0.037 ...
    0.033 0.037 0.037 0.034 0.036 0.035 0.036 0.037 ...
    0.035 0.036 0.036 0.037 0.035 0.035 0.033 0.033 ...
    0.035 0.036 0.037 0.034];

weights = weights / sum(weights); % Ensure sum = 1

% ---------------------------------------------------
% Triangular distribution parameters (N × 3)
% Columns: [Minimum, Most Likely, Maximum]
% Values must be between 0 and 1
% ---------------------------------------------------
triParams = [
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
```

```
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.75 1;
    0 0.5 1;
    0 0.75 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;
    0 0.5 1;


];

%% ============== MODEL EXECUTION ==================

SafetyIndex = zeros(numSim,1);

for i = 1:numSim

    factorScores = zeros(N,1);

    for j = 1:N

        a = triParams(j,1);
        b = triParams(j,2);
        c = triParams(j,3);

        % Triangular random number generation
        u = rand;
        if u <= (b-a)/(c-a)
            factorScores(j) = a + sqrt(u*(b-a)*(c-a));
        else
            factorScores(j) = c - sqrt((1-u)*(c-b)*(c-a));
        end

    end

    % Weighted aggregation
    SafetyIndex(i) = sum(weights' .* factorScores);
```

```
end

%% ============== RESULTS ============================

MeanSafety   = mean(SafetyIndex);
MedianSafety = median(SafetyIndex);
StdSafety    = std(SafetyIndex);
CI90         = prctile(SafetyIndex,[5 95]);

fprintf('\n===== SAFETY ASSESSMENT RESULTS =====\n');
fprintf('Mean Safety Index        : %.3f\n', MeanSafety);
fprintf('Median Safety Index      : %.3f\n', MedianSafety);
fprintf('Standard Deviation       : %.3f\n', StdSafety);
fprintf('90%% Confidence Interval  : [%.3f  %.3f]\n', CI90(1), CI90(2));

%% ============== SAFETY LEVEL CLASSIFICATION =======

Unsafe   = sum(SafetyIndex < 0.40)/numSim * 100;
Moderate = sum(SafetyIndex >= 0.40 & SafetyIndex < 0.70)/numSim * 100;
Safe     = sum(SafetyIndex >= 0.70)/numSim * 100;

fprintf('\n===== SAFETY LEVEL PROBABILITY =====\n');
fprintf('Unsafe   : %.2f %%\n', Unsafe);
fprintf('Moderate : %.2f %%\n', Moderate);
fprintf('Safe     : %.2f %%\n', Safe);

%% ============== VISUALIZATION ======================

figure;
histogram(SafetyIndex,40,'Normalization','pdf');
xlabel('Overall Safety Index');
ylabel('Probability Density');
title('Monte Carlo Simulation of Construction Safety Level');
grid on;
```

Annex 2: Survey Questionnaire

Factors Affecting Safety in Irrigation Projects in Nepal

You are invited to participate in an academic survey conducted as part of a Master's thesis in Construction Management at Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal. This study aims to identify and evaluate key factors affecting safety in irrigation projects. Participation is voluntary and responses will remain confidential.

Do you agree to participate in this survey?

- (●) Yes
- ( ) No

Survey Questionnaire

» General Information

Have you worked in Irrigation Projects under Department of Water Resources and Irrigation

- ( ) Yes
- ( ) No

Your role in irrigation projects

- ( ) Project Manager (Governmental)
- ( ) Site Engineer (Governmental)
- ( ) Safety Officer
- ( ) Consultant
- ( ) Contractor's Representative/ Engineer
- ( ) Other (Please specify)

Please specify your role

_____

Years of experience in irrigation construction projects

- ( ) Less than 5 years
- ( ) 5–10 years
- ( ) 10–15 years
- ( ) More than 15 years

Types of irrigation projects you have worked on

- [ ] Canal construction
- [ ] Pipeline systems
- [ ] Diversion structures
- [ ] Headworks
- [ ] Other (Please specify)

Please specify.

_____

» Based on your professional experience, please assess the importance of the following factors in influencing occupational safety in irrigation projects.

↓

_____

» Worker-Related Factors

Insufficient safety training

Very Low Impact | Low Impact | Moderate Impact | High Impact | Very High Impact

Improper use of Personal Protective Equipment (PPE)

Very Low Impact | Low Impact | Moderate Impact | High Impact | Very High Impact

Unsafe worker behavior

Very Low Impact | Low Impact | Moderate Impact | High Impact | Very High Impact

» Organizational / Policy-Related Factors

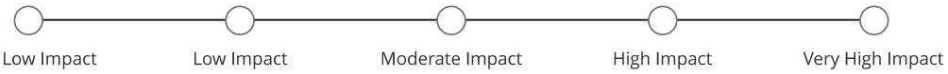
Absence of safety policies

Very Low Impact | Low Impact | Moderate Impact | High Impact | Very High Impact

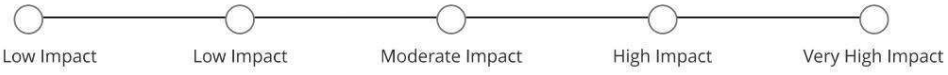
Low management commitment towards safety

Very Low Impact | Low Impact | Moderate Impact | High Impact | Very High Impact

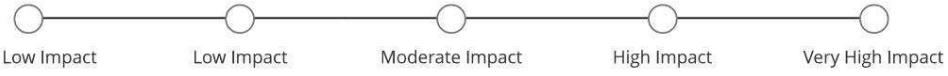
Poor reporting culture regarding accidents and near misses



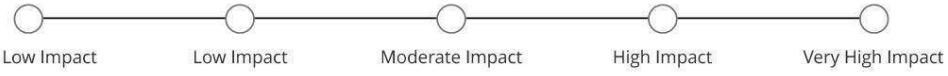
Insufficient safety budget



Weak safety culture

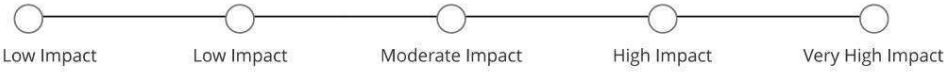


Poor documentation of accidents and near misses

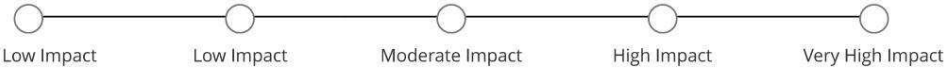


» Management & Supervision Factors

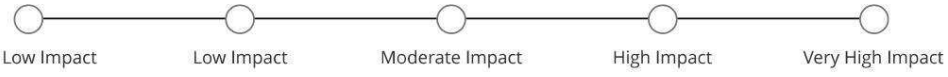
Weak site supervision



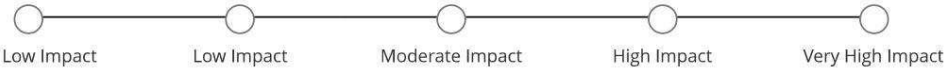
Inadequate safety inspection



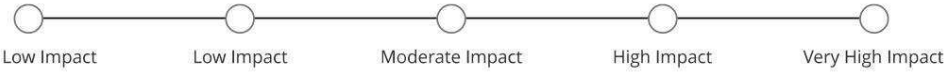
Lack of safety officer



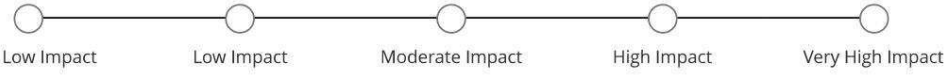
Poor subcontractor management



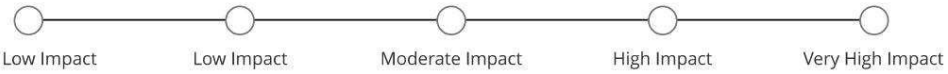
Inadequate work planning



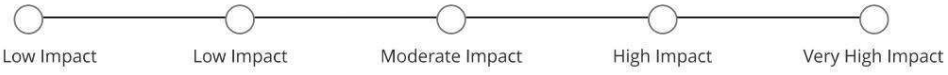
Lack of toolbox talks



Lack of proper authorization before starting hazardous work

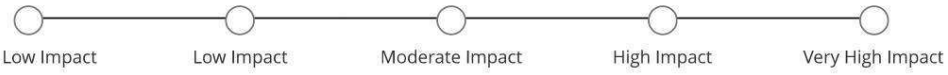


Lack of clear safety instructions from supervisors to workers

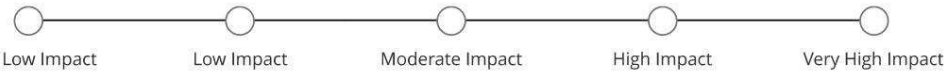


» Technical / Equipment Factors

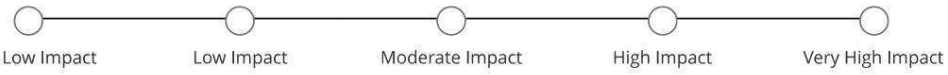
Improper equipment use



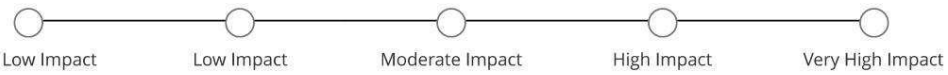
Poor machinery maintenance



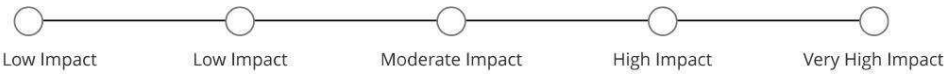
Unsafe scaffolding



Inadequate machine guarding

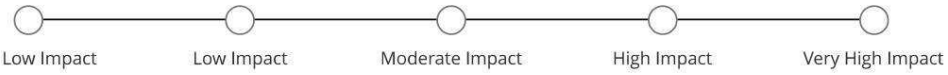


Material handling risks

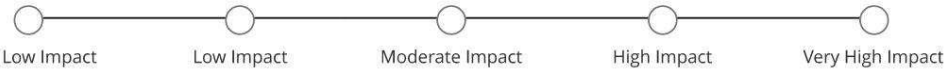


» Site / Procedural Factors

Poor housekeeping



Unsafe site layout



Excavation hazards

Very Low Impact | Low Impact | Moderate Impact | High Impact | Very High Impact

Slippery or unstable surfaces

Very Low Impact | Low Impact | Moderate Impact | High Impact | Very High Impact

Poor emergency preparedness

Very Low Impact | Low Impact | Moderate Impact | High Impact | Very High Impact

Adverse weather exposure

Very Low Impact | Low Impact | Moderate Impact | High Impact | Very High Impact

» Based on your professional experience, please indicate how frequently the following safety-related factors are actually implemented in irrigation projects.

↓

» Worker-Related Factors

Provision of safety training to workers

Never | Rarely | Sometime | Often | Always

Consistent use of Personal Protective Equipment (PPE)

Never | Rarely | Sometime | Often | Always

Compliance of workers with safe work practices

Never | Rarely | Sometime | Often | Always

» Organizational / Policy-Related Factors

Existence of formal safety policies

Never | Rarely | Sometime | Often | Always

Management commitment to site safety

Never Rarely Sometime Often Always

Reporting of accidents and near-miss incidents

Never Rarely Sometime Often Always

Allocation of budget for safety measures

Never Rarely Sometime Often Always

Promotion of a positive safety culture

Never Rarely Sometime Often Always

Maintenance of safety-related documentation

Never Rarely Sometime Often Always

» Management & Supervision Factors

Adequate on-site safety supervision

Never Rarely Sometime Often Always

Regular safety inspections

Never Rarely Sometime Often Always

Availability of designated safety personnel

Never Rarely Sometime Often Always

Safety management of subcontractors

Never Rarely Sometime Often Always

Safety consideration during work planning

Never Rarely Sometime Often Always

Conduction of toolbox talks before work

Never Rarely Sometime Often Always

Ensuring proper authorization before starting hazardous work

Never Rarely Sometime Often Always

Clear safety instructions from supervisors to workers

Never Rarely Sometime Often Always

» Technical / Equipment Factors

Proper use of construction equipment

Never Rarely Sometime Often Always

Regular maintenance of machinery

Never Rarely Sometime Often Always

Ensuring safety condition of scaffolding and access systems

Never Rarely Sometime Often Always

Availability of machine safety guarding

Never Rarely Sometime Often Always

Safe material handling practices

Never Rarely Sometime Often Always

» Site / Procedural Factors

Proper site housekeeping practices

Never Rarely Sometime Often Always

Safety of site layout and access routes

Never Rarely Sometime Often Always

Safety measures for excavation works

Never Rarely Sometime Often Always

Management of slippery or unstable surfaces

Never Rarely Sometime Often Always

Emergency preparedness and response planning

Never Rarely Sometime Often Always

Measures to manage weather-related safety risks

Never Rarely Sometime Often Always

Thank you for your valuable time and contribution.

Annex 3: Acceptance Mail for 18th IOE Graduate Conference

[IOEGC18] Editor Decision External Inbox ×

Dr. Ram Krishna Regmi <ioegc17@gmail.com> Mon, Apr 27, 2:40 PM (4 days ago)

to me

Sujata Gautam:

We have reached a decision regarding your submission to 18th IOE Graduate Conference, "Application of Principal Compon for Assessing Construction Safety Performance in Irrigation Projects in Nepal".

Our decision is to: Accept Submission

With Warm Regards,
IOEGC-18 Editorial Team

Annex 4: Originality Report

iThenticate

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PAPER NAME

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AUTHOR

Sujata Gautam

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