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Identification and Assessment of Risk Factors in Hydropower Projects: Development of a Hydropower Risk Index (HRI) for Nepal

By

Paramatma Baniya

A THESIS

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

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Head

Department of Civil Engineering

Pulchowk Campus, Institute of Engineering

Pulchowk, Lalitpur

Nepal

DECLARATION

I hereby declare that the thesis entitled **"Identification and Assessment of Risk Factors in Hydropower Projects: Development of a Hydropower Risk Index (HRI) for Nepal"**, submitted to the Department of Civil Engineering in partial fulfillment of the requirements for the degree of Master of Science in Construction Management, is a record of original work carried out by me under the academic guidance of Asst. Prof. Mahendra Raj Dhital and Assoc. Prof. Nagendra Bahadur Amatya, Institute of Engineering, Pulchowk Campus. This thesis contains only work completed by me except for the information obtained from other sources, which has been duly cited and acknowledged.

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Paramatma Baniya

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CERTIFICATE OF THESIS APPROVAL

The undersigned certify that we have read and recommended to the Institute of Engineering for acceptance of a thesis entitled **"Identification and Assessment of Risk Factors in Hydropower Projects: Development of a Hydropower Risk Index (HRI) for Nepal"**, submitted by Paramatma Baniya in partial fulfillment of the requirements for the degree of Master of Science in Construction Management.

………………………………………………	………………………………………………
Supervisor: Asst. Prof. Mahendra Raj Dhital Civil Engineering Department IOE, Pulchowk Campus	Supervisor: Assoc. Prof. Nagendra Bahadur Amatya Applied Science and Chemical Engineering Department IOE, Pulchowk Campus
………………………………………………	………………………………………………
External Examiner: Er. Subash Kumar Bhattarai Visiting Faculty Construction Management Centre for Post Graduate Studies Nepal Engineering College (nec-CPS)	Program Coordinator: Asst. Prof. Mahendra Raj Dhital M.Sc. in Construction Engineering and Management Program Civil Engineering Department IOE, Pulchowk Campus

Date: 23rd April, 2026

ABSTRACT

Hydropower is a cornerstone of Nepal's energy strategy; however, projects in this sector routinely suffer schedule delays, cost overruns and operational inefficiencies, largely due to the absence of a standardized, comprehensive risk assessment framework. To address this critical gap, this study develops a Hydropower Risk Index (HRI) tailored to Nepal's unique geological, institutional and socio-environmental context. Through expert validation, pilot testing and a structured questionnaire survey administered to hydropower professionals in the Kathmandu Valley, the study identifies and assesses 34 key risk factors spanning technical, financial, environmental, social and managerial dimensions. Data were analysed using factor weighting, normalization and indexing methods to systematically quantify and prioritize risks. The HRI classifies hydropower projects into five risk levels as very low, low, medium, high and very high, enabling stakeholders to anticipate and manage project challenges more effectively. Validation through Cronbach's alpha reliability testing ($\alpha > 0.70$), sensitivity analysis and correlation analysis confirmed the model's internal consistency and robustness. Findings reveal that Nepal's hydropower projects are most critically exposed to financial management deficiencies, challenging geological conditions, regulatory delays and stakeholder disputes. The HRI offers both quantitative risk assessment tool and actionable mitigation strategies, serving as a practical decision-support instrument for policymakers, project planners and managers to enhance project performance and advance the long-term sustainability of Nepal's hydropower sector.

Keywords:

Hydropower projects, Risk factors, Hydropower Risk Index (HRI), Risk mitigation, Project performance

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Paramatma Baniya
Roll No.: 080MSCoM013

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
BIM	Building Information Modeling
BOOT	Build Own Operate Transfer
EIAs	Environmental Impact Assessments
EPC	Engineering, Procurement and Construction
GLOFs	Glacial Lake Outburst Floods
HRI	Hydropower Risk Index
JICA	Japan International Cooperation Agency
LPI	Labor Productivity Index
O&M	Operation and Maintenance
SPSS	Statistical Package for the Social Sciences
WB	World Bank
MoEWRI	Ministry of Energy, Water Resources & Irrigation

CHAPTER 1: INTRODUCTION

1.1 Background

Hydropower development plays a vital role in Nepal’s infrastructure expansion, making a substantial contribution to energy security, economic progress, and regional connectivity (Chaudhary, 2024; Bhatt & Joshi, 2024). Nevertheless, hydropower construction projects are highly complex and are subject to a wide range of risks that may negatively influence project cost, schedule, and overall performance outcomes (Abd El-Karim et al., 2017; Gunasekaran et al., 2014). These risks stem from a range of sources, including financial uncertainties, technical limitations, environmental conditions, regulatory delays, labour availability, and political instability (Tang et al., 2013; Shaktawat & Vadhera, 2021; Rauzana, 2016).

Despite growing awareness of these challenges, the hydropower sector in Nepal continues to lack a systematic and standardized framework for risk identification, assessment, and prioritization (Tripathi et al., 2017; Sudirman & Hardjomuljadi, 2011). Risk management practices are often reactive, based on subjective judgments or incomplete data, resulting in inconsistent mitigation measures and inefficient decision-making (Rezakhani; Tessema et al., 2022). This contributes to widespread issues such as cost overruns, project delays, and compromised quality undermining both investor confidence and long-term sustainability (Chileshe & Boadua Yirenkyi-Fianko, 2012; Goji Tipi, al.).

This study aims to overcome these limitations by formulating a Hydropower Risk Index (HRI) tailored to the hydropower sector in Nepal. The proposed index combines expert judgment, empirical evidence, and analytical methods to evaluate the relative likelihood and impact of major risk factors (Agarwal & Kansal, 2020; Maharjan, 2025). By providing a structured, data-driven tool for risk assessment, the HRI aims to support more resilient project planning, informed decision-making, and improved project outcomes. Ultimately, this study aims to promote a proactive approach to risk management and support the progress of sustainable hydropower development in Nepal (Shaktawat & Vadhera, 2021; Tang et al., 2013).

Recent studies published in well-established, internationally recognized journals demonstrate that hydropower project risk assessment has increasingly shifted toward structured, quantitative, and evidence-based approaches. Studies published in journals such as Energy, Energy Policy, Heliyon, and HBRC Journal highlight the application of composite indices, multi-criteria decision-making approaches, and expert judgment–based evaluation frameworks to systematically detect and rank technical, financial, environmental, and regulatory risks (Agarwal & Kansal, 2020; Shaktawat & Vadhera, 2021; Tang et al., 2013; Yucesan & Kahraman, 2019). Similarly, recent research has highlighted the importance of utilizing Key Performance Indicators (KPIs) to evaluate the success of small-scale hydropower projects, thereby underscoring the necessity for a systematic approach to risk assessment (Bhattarai et al., 2024). These studies provide a strong methodological foundation and establish internationally accepted practices for hydropower risk analysis, against which new research can be positioned and evaluated.

While several risk dimensions identified in international studies are also relevant to Nepalese hydropower projects, differences are expected due to Nepal's unique geological, institutional, and socio-environmental context. Compared to many international cases, Nepalese projects are more exposed to complex mountainous terrain, fragile geology, policy uncertainty, and community-related challenges, which can alter the relative importance of specific risk factors (Chaudhary, 2024; Bhatt & Joshi, 2024). Therefore, this study examines the extent to which international risk assessment findings align with the Nepalese context and systematically explains observed differences using evidence from literature, expert consultation, and standardized analytical tools. By doing so, the research aims to demonstrate that its findings are not based on individual perception but are consistent with globally recognized methodologies while remaining contextually justified.

1.2 Statement of problem

Hydropower projects, like other large-scale infrastructure undertakings, are exposed to a wide range of uncertainties that frequently translate into significant risks. These risks often result in cost overruns, time delays, and disputes among stakeholders (Abd El-Karim et al., 2017; Chileshe & Boadua Yirenkyi-Fianko, 2012). In developing countries such as Nepal, these issues are more pronounced due to the limited adoption of structured and systematic risk management approaches (Tripathi et al., 2017; Shaktawat & Vadhera, 2021). The lack of standardized frameworks for identifying and assessing risks not only hampers project performance but also compromises long-term sustainability (Gunasekaran et al., 2014; Tessema et al., 2022).

In Nepal's hydropower sector, risk assessment practices remain largely qualitative, informal, and inconsistent across projects (Bhatt & Joshi, 2024; Chaudhary, 2024). At present, there is no robust, data-driven tool such as a Hydropower Risk Index (HRI) to systematically quantify and prioritize the risks specific to the sector and the national context (Tripathi et al., 2017; Agarwal & Kansal, 2020). Consequently, project planners and decision-makers face persistent challenges in managing uncertainties effectively and implementing timely mitigation strategies (Sudirman & Hardjomuljadi, 2011; Tang et al., 2013).

This study aims to bridge this gap by creating a Hydropower Risk Index tailored specifically to the Nepalese context. The goal is to establish a structured, evidence-based methodology for identifying and assessing risk factors, enabling more informed decision-making, improved project performance, and enhanced resilience in Nepal's hydropower development initiatives (Shaktawat & Vadhera, 2021; Rezakhani).

1.3 Research Questions

1. What are the critical risk factors affecting the performance and outcomes of hydropower projects?
2. How can a Hydropower Risk Index (HRI) be developed to quantify and prioritize these risks for effective management?
3. What risk mitigation measures can be recommended based on the analysis of the developed Hydropower Risk Index (HRI)?

1.4 Research Objectives

The primary objective of this study is identification and assessment of risk factors in hydropower projects: Development of a Hydropower Risk Index (HRI) for Nepal. Whereas, the secondary objectives are as follows:

1. To identify and evaluate critical risk factors influencing the performance of hydropower projects.

2. To develop a structured and context-specific Hydropower Risk Index (HRI) that quantifies the relative impact of identified risk factors.
3. To recommend appropriate risk mitigation measures grounded in the analysis of the developed risk index.

1.5 Significance of the Study

Hydropower projects are inherently complex undertakings characterized by multifaceted uncertainties that persist throughout their entire lifecycle. When risk factors are left unidentified or inadequately addressed, they frequently result in substantial cost overruns, schedule delays and a decline in overall project quality. Although Nepal possesses significant hydropower potential, the sector still lacks a systematic and quantitative risk assessment framework, which hinders effective project planning and implementation. This study directly addresses that deficiency by systematically identifying, classifying and evaluating the risk factors specific to hydropower projects within the Nepalese context.

The primary contribution of this study is the formulation of a Hydropower Risk Index (HRI), a composite quantitative framework developed to evaluate the likelihood and severity of risks. By translating complex, multidimensional risk data into a single interpretable metric, the HRI provides project planners, engineers, contractors, and decision-makers with a practical instrument for prioritizing risks and designing targeted mitigation strategies. Drawing on internationally validated methods including normalization, expert-based weighting and sensitivity analysis, the index is both methodologically rigorous and contextually adapted to reflect Nepal's unique geological, hydrological and socio-political conditions.

By providing a structured risk evaluation framework, this study contributes significantly to enhancing risk-informed decision-making, promoting efficient resource utilization and improving the overall reliability and performance of hydropower project implementation in Nepal. Beyond its immediate practical utility, the research advances the academic understanding of composite index development in infrastructure risk assessment and supports a broader transition from reactive to proactive risk management practices. Ultimately, the HRI offers a solid foundation for sustainable hydropower development, with long-term relevance for policy formulation, institutional capacity building and Nepal's energy security objectives.

1.6 Scope and Limitations of the Study

A. The study is centered on hydropower projects within Nepal, with emphasis on identifying and evaluating risks and formulating a risk index. It relies on insights gathered from key stakeholders actively working in the sector, including developers, contractors, consultants, engineers, and relevant regulatory agencies. The developed

Hydropower Risk Index (HRI) is specifically calibrated to the Nepalese context and is not intended for direct generalization to hydropower projects in other geographical or regulatory settings without appropriate adaptation.

B. The sampling for this study incorporates professionals from the Kathmandu Valley only, targeting stakeholders directly involved in hydropower project implementation. Although stratified representation was ensured across client, contractor, and consultant categories, other professional strata such as financiers, insurance providers, and community representatives were not fully incorporated, in order to limit the complexity of the research and maintain a focused scope.

C. The risk factors and their respective weights used in the construction of the HRI are derived primarily from survey-based expert perceptions and existing literature. As hydropower risks are inherently dynamic, they are influenced by evolving policies, market conditions, climate variability, and site-specific geological conditions. So, the index reflects a snapshot in time and will require periodic updates to remain valid and applicable across varying project scales and phases.

CHAPTER 2: LITERATURE REVIEW

This chapter examines previous studies, theoretical concepts, and established frameworks related to risk management in hydropower projects. It identifies key factors and sub-factors influencing project outcomes, including technical, financial, environmental, regulatory, and socio-political risks. Additionally, it highlights lessons from international practices, limitations of current approaches, and the relevance of index-based models. The review also identifies research gaps, particularly in Nepal's context, and provides a foundation for developing the Hydropower Risk Index (HRI), ensuring the study is well-grounded in relevant literature.

2.1 Introduction

Hydropower projects are critical elements of national energy strategies, particularly in countries like Nepal that possess abundant water resources and demand sustainable energy solutions. Hydropower projects involve significant complexity and are exposed to a wide range of risks that may adversely influence project costs, timelines, and overall efficiency (Chaudhary, 2024; Bhatt & Joshi, 2024). Therefore, gaining a clear understanding of these risks and evaluating them through a structured approach is crucial for effective project execution and ensuring long-term sustainability (Shaktawat & Vadhera, 2021).

In Nepal, the growth of the hydropower sector plays an important role in economic development, but it is constrained by issues such as unstable political conditions, ineffective bureaucratic processes, and environmental restrictions (Chaudhary, 2024). Despite the sector's immense potential, persistent issues including financing limitations, regulatory bottlenecks, and community-level opposition continue to impede progress (Bhatt & Joshi, 2024).

2.2 The Need for a Hydropower Risk Index (HRI)

To address these complexities, developing a Hydropower Risk Index (HRI) is essential. This index aims to identify, quantify, and prioritize risk factors to support better planning and mitigation strategies (Agarwal & Kansal, 2020; Tripathi et al., 2017). In Nepal, a similar approach using fuzzy logic was employed to assess risks in BOOT hydropower projects, effectively integrating expert opinions and uncertainties associated with key risk domains (Tripathi et al., 2017).

2.3 International Perspectives on Hydropower Risk

Evidence from global studies further emphasizes the importance of adopting systematic risk management practices in hydropower development. For example, research conducted in Indonesia found that weak coordination among stakeholders and ineffective distribution of risks were major factors leading to project delays and increased costs (Sudirman & Hardjomuljadi, 2011).

In China, the fast-paced expansion of hydropower projects without strong risk management frameworks has led to environmental damage and social tensions, highlighting the importance of including environmental and social aspects within risk assessment indices (Tang et al., 2013). Early-stage financial risk evaluation is another Critical component. Integrating risk assessments during the planning phase enhances the financial viability and resilience of hydropower projects (Agarwal & Kansal, 2020). In the context of Nepal, survey-based studies have revealed that rework-related expenses and delays in contractor schedule approvals are key contributors to both cost escalation and project delays, supporting the development of an integrated risk index (Bhattarai et al., 2024).

2.4 Framework for Adaptive Risk Assessment

Moreover, adopting a comprehensive and adaptive framework is necessary to accommodate changing project conditions over time (Shaktawat & Vadhera, 2021). The literature collectively supports the formulation of a localized, flexible, and empirically grounded HRI. Such an index should account for technical, financial, regulatory, environmental, and socio-political risks, and be validated through stakeholder engagement and contextual data analysis (Bhatt & Joshi, 2024 ; Chaudhary, 2024). As a decision-support tool, the HRI can enable project stakeholder to proactively manage risks and enhance hydropower project outcomes across Nepal.

Summing up, existing research highlights the multifaceted risk landscape of hydropower projects and the urgent need for systematic tools for risk identification and evaluation. The proposed HRI seeks to address this gap by offering a structured, quantitative solution grounded in both national realities and international best practices (Sudirman & Hardjomuljadi, 2011; Tang et al., 2013; Shaktawat & Vadhera, 2021).

2.5 Broader Construction Risk Factors and Relevance to Hydropower

Hydropower projects are vital infrastructure initiatives, especially in countries like Nepal where there is an abundance of water resources. These projects, however, face numerous risks that can significantly affect their timeline, budget, and overall performance (Abd El-Karim et al., 2017; Gunasekaran et al., 2014). Identifying and evaluating these risk factors systematically is essential for ensuring successful project delivery.

Construction-related risks are not unique to Nepal; global studies reveal common Critical issues such as poor planning, inadequate funding, resource constraints, and labor inefficiencies (Chileshe & Boadua Yirenkyi-Fianko, 2012; Rauzana, 2016). These risks often manifest as delays, cost overruns, or compromised quality, and highlight the need for structured risk management approaches across all project phases (Goji Tipili et al.; Rezakhani).

In Ethiopia, major risks identified included lack of proper project planning, delay in approvals, and resource shortages, all of which are applicable in hydropower construction settings (Tessema et al., 2022). In Indonesia, similar studies emphasized financial uncertainties and ineffective stakeholder coordination as core issues (Rauzana, 2016). These international insights support the argument for a risk assessment tool tailored to context-specific challenges.

In Nepal, labor productivity and workforce-related risks remain pressing concerns that influence project efficiency and completion time (Maharjan, 2025). Additionally, risks affecting cost are especially significant during the initial planning stages, further supporting the call for an early-phase evaluation mechanism (Gunasekaran et al., 2014).

The literature also emphasizes categorizing risks into distinct domains such as technical, financial, regulatory, and environmental for effective management (Abd El-Karim et al., 2017; Rezakhani). A Hydropower Risk Index (HRI), therefore, should be developed with a multi-dimensional structure capable of quantitatively assessing risk impact and probability to aid prioritization.

Overall, the reviewed studies advocate for localized risk identification strategies that consider regional socio-economic, environmental, and technical conditions. Incorporating these factors into an HRI will improve decision-making, reduce project uncertainty, and enhance overall outcomes (Chileshe & Boadua Yirenkyi-Fianko, 2012; Tessema et al., 2022; Maharjan, 2025).

Summing up, the development of a Hydropower Risk Index rooted in empirical evidence and supported by international and regional insights can serve as a vital decision-support tool. This tool will help stakeholders anticipate, assess, and mitigate risks in a systematic manner, ensuring more efficient and sustainable execution of hydropower projects (Rauzana, 2016; Gunasekaran et al., 2014; Abd El-Karim et al., 2017).

Based on a thorough review of scholarly studies, 41 risk factors were extracted and organized into ten main categories relevant to hydropower development projects. Table 2.1 presents these categories alongside their associated risk factors and the corresponding literature sources from which they were derived.

Table 2. 1 Risk Categories, Associated Factors, and Supporting References

Risk Categories	Risk Factors	Derived From
Design Risks	Incomplete geological & hydrological investigation	Abd El-Karim et al., 2017; Agarwal & Kansal, 2020
	Poor dam design or tunnel alignment	Abd El-Karim et al., 2017; Agarwal & Kansal, 2020
	Frequent design revisions during construction	Abd El-Karim et al., 2017; Chileshe & Yirenkyi-Fianko, 2012; Rauzana, 2016
	Difficult topography & terrain	Chileshe & Boadua Yirenkyi-Fianko, 2012; Chaudhary, 2024
	Lack of adaptability to remote site conditions	Chileshe & Boadua Yirenkyi-Fianko, 2012; Maharjan, 2025
Management and Coordination Risks	Poor coordination between contractors, consultants & local authorities	Sudirman & Hardjomuljadi, 2011; Tripathi et al., 2017
	Inexperience in managing hydropower complexity	Gunasekaran et al., 2014; Sudirman & Hardjomuljadi, 2011
	Ineffective stakeholder communication	Tripathi et al., 2017; Shaktawat & Vadhera, 2021
	Ineffective inter-agency and cross-border coordination	Tang et al., 2013; MRC Guidelines; Shaktawat & Vadhera, 2021
Resource Risks	Remote access leads to supply delays	Maharjan, 2025; Shaktawat & Vadhera, 2021
	Skilled hydropower workforce shortages	Maharjan, 2025; Chaudhary, 2024
	Inefficient procurement and management of spare parts and consumables	Sudirman & Hardjomuljadi, 2011; Yucesan & Kahraman, 2019; Oksuz & Brlek, 2023
	Equipment inaccessibility or unsuitability for terrain	Shaktawat & Vadhera, 2021; Tripathi et al., 2017

Financial Risks	Reliability and creditworthiness of the Offtaker (Buyer)	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024
	Inadequate allocation and utilization of contingency budgets	Agarwal & Kansal, 2020; Li et al., 2023; Abd El-Karim et al., 2017
	Grid availability and dispatch risk	Tang et al., 2013; Bhatt & Joshi, 2024
	Delay in financial closure	Agarwal & Kansal, 2020; Tang et al., 2013
	Difficulty in securing private sector investment	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024
	Underestimation of tunnel or powerhouse costs	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024
Economic Risks	Cost escalation due to imported machinery	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024
	Foreign exchange risks for loan repayments	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024
	Inflation during long project durations	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024
Political and Legal Risks	Political instability and frequent leadership changes	Chaudhary, 2024; Bhatt & Joshi, 2024; Shaktawat & Vadhera, 2021
	Unstable regulatory framework	Rezakhani; Rauzana, 2016
	Bureaucratic delays in permits	Rezakhani; Rauzana, 2016
	Local-level opposition or interference	Shaktawat & Vadhera, 2021; Rezakhani
Environmental Risks	High environmental sensitivity of project area	Chaudhary, 2024; Sudirman & Hardjomuljadi, 2011
	Landslides, GLOFs, monsoon floods	Chaudhary, 2024; Tripathi et al., 2017
	Delays due to Environmental Impact Assessments (EIAs)	Sudirman & Hardjomuljadi, 2011; Tripathi et al., 2017
	Poor implementation of environmental mitigation measures	MRC Guidelines; Shaktawat & Vadhera, 2021; Tang et al., 2013
Social Risks	Land acquisition disputes	Abd El-Karim et al., 2017; Chileshe & Boadua Yirenkyi-Fianko, 2012
	Inadequate compensation or resettlement	Abd El-Karim et al., 2017; Goji Tipili et al.
	Cultural/indigenous rights violations	Goji Tipili et al.; Chileshe & Boadua Yirenkyi-Fianko, 2012
	Protest and local strikes	Goji Tipili et al.; Tripathi et al., 2017

Contractual/Legal Risks	Ambiguous risk-sharing clauses in BOOT contracts	Tripathi et al., 2017; Gunasekaran et al., 2014
	Claims and disputes over design responsibility	Gunasekaran et al., 2014; Tripathi et al., 2017
	International arbitration complexities	Tripathi et al., 2017; Gunasekaran et al., 2014
Operational Risks	Delays in grid connection	Sudirman & Hardjomuljadi, 2011; Tang et al., 2013
	Generation below expected capacity due to poor hydrological prediction	Sudirman & Hardjomuljadi, 2011; Tang et al., 2013
	O&M challenges post-construction	Shaktawat & Vadhera, 2021; Sudirman & Hardjomuljadi, 2011
	Inadequate emergency preparedness and disaster response planning	Pescaroli et al., 2020; Oksuz & Brlek, 2023; Sudirman & Hardjomuljadi, 2011

2.6 Methodological Rigor in Instrument Design

Developing a structured and reliable research instrument is an essential prerequisite for empirical risk assessment studies. The design and validation of questionnaires enable the collection of consistent and interpretable data, particularly when investigating perceptions of risk in complex infrastructure projects such as hydropower (Ranganathan & Caduff, 2023; Ranganathan et al., 2024). Questionnaire-based surveys provide a systematic means of capturing expert opinions and field experiences, which form the foundation for constructing indices like the Hydropower Risk Index (HRI). As noted by Pérez-Rivas et al. (2023), expert validation ensures that each item in an instrument accurately represents the construct being measured, while Abu Hassan et al. (2006) emphasize the necessity of pilot testing to identify ambiguities and inconsistencies before large-scale deployment. In a similar vein, Khanal & Chhetri (2024) showed that conducting pilot studies enhances the reliability and validity of survey instruments, thereby increasing the precision of measurements.

2.7 Digital Data Collection and Likert Scales in Risk Perception

The effective use of digital tools such as KoboToolbox has further enhanced the efficiency of survey data collection in construction and infrastructure projects. KoboToolbox provides real-time data synchronization, geotagging, and offline capabilities that support research conducted in remote hydropower locations (Roy et al.). Digital data collection systems minimize transcription errors and enhance data integrity, which is crucial for risk quantification and statistical analysis. Once data are gathered, Likert-type scales serve as a widely accepted method for quantifying perceptions and attitudes toward risk factors (Sullivan & Artino, 2013). The use of such ordinal scales facilitates the computation of composite measures, allowing researchers to transform subjective responses into quantifiable indices (Pescaroli et al., 2020). The clarity of Likert-scale responses supports consistency in responses across experts, particularly when assessing qualitative aspects such as stakeholder communication, construction safety, and environmental risks in hydropower development.

2.8 Theoretical and Conceptual Framing of Risk

Developing a reliable index such as the HRI requires a structured research design that integrates theoretical and conceptual frameworks. Grant & Osanloo (2014) highlighted that the theoretical framework serves as the blueprint guiding the research process, linking existing theories to empirical inquiry. Luft et al. (2022) further argued that theoretical and conceptual frameworks function as scaffolds that position the research within existing scholarly discourse. In applied research within construction and hydropower sectors, Jabareen (2009) noted that conceptual frameworks serve to connect theoretical concepts with the practical aspects of identifying and evaluating risks. Similarly, Lindgreen et al. (2021) highlighted that conceptual frameworks are developed through an iterative process, enabling them to reflect the evolving interactions among various risk domains, including financial, technical, environmental, and social dimensions. Within this context, integrating conceptual clarity ensures that the resulting composite risk index not only measures observable risk events but also reflects underlying systemic interdependencies.

2.9 Statistical Foundations: Descriptive, Correlation, Composite Index Methods & Chi-squared Test Analysis

From a methodological standpoint, quantitative analysis is fundamental to the development of composite indices. R. W. Cooksey (2020) explains that descriptive measures including the mean, standard deviation, and frequency distributions serve as an essential basis for understanding data patterns prior to undertaking inferential analysis. Correlation analysis further assists in examining relationships among risk factors, supporting prioritization and the identification of dominant risk categories (Rodgers & Nicewander, 1988). These statistical tools enable the transformation of raw expert judgments into standardized measures, which form the basis of risk weighting in the HRI. The development of composite indices can benefit from expert-opinion-based weighting procedures (Chen et al., 2022). Incorporating structured expert elicitation not only captures diverse perspectives but also mitigates subjectivity in assigning risk importance. In hydropower applications, such structured weighting is particularly valuable for evaluating complex interdependencies between geological, hydrological, and socio-economic factors. The Chi-square goodness-of-fit test is commonly applied to assess whether observed data aligns with a specified theoretical distribution, by evaluating differences between observed and expected frequencies across categories (NDSU Chi-Squared Test, 2020). It involves computing a Chi-square statistic based on deviations between observed and expected values and interpreting the result using degrees of freedom and probability tables (NDSU Chi-Squared Test, 2020). The test allows researchers to evaluate whether the assumed data distribution is appropriate and aids in hypothesis testing by helping determine if the null hypothesis should be accepted or rejected (NDSU Chi-Squared Test, 2020).

2.10 Robustness through Sensitivity Analysis

The inclusion of sensitivity analysis enhances the robustness of index development. Sensitivity analysis examines how changes in input weights influence the resulting index values, thereby enhancing clarity and accountability in the risk evaluation process (Saltelli et al., 2019). Within hydropower research, (Barendrecht et al.) and Gao et al. (2023) highlight the need to explore alternative weighting schemes to determine which factors exert the greatest impact on the overall risk score. In a similar vein, participatory sensitivity analysis incorporates stakeholder input, improving both the methodological robustness and social acceptance of the composite index (Barendrecht et al.). These approaches minimize bias and improve the interpretability of risk indices for decision-making purposes. As a result, the Hydropower Risk Index can provide both project-specific and comparative assessments across multiple sites.

2.11 Empirical Risk Evaluation in Hydropower Projects

Empirical research on hydropower developments has identified a wide range of risk areas that demand structured mitigation approaches. Li et al. (2023) employed an enhanced fuzzy evidential reasoning framework to assess risks in engineering, procurement, and construction (EPC) hydropower schemes. Their results highlighted that combining multiple evaluation criteria through fuzzy logic improves decision-making in uncertain environments, particularly where geological and hydrological conditions are highly variable. In a similar vein, Yucesan

& Kahraman (2019) proposed a Pythagorean fuzzy analytical hierarchy process (AHP) to rank operational risks and recommend suitable preventive measures. The integration of fuzzy logic with multi-criteria decision-making techniques allows for more accurate recognition of key risks, supporting the formulation of effective mitigation strategies. Within the Nepalese setting, Ojha et al. (2025) analyzed the Super Madi Hydropower Project and identified principal risk factors such as geological instability, contractor inefficiency, and policy inconsistency, while also suggesting context-specific mitigation measures for each category.

2.12 Typologies of Mitigation Strategies in Hydropower

Risk mitigation in hydropower projects encompasses technical, financial, contractual, and environmental strategies. (Braeckman) and Oksuz & Brlek (2023) examined mitigation in cascade hydropower projects, emphasizing proactive maintenance, automation, and early-warning monitoring as technical measures to reduce system vulnerability. Financial and contractual risk-sharing mechanisms, as discussed by (Braeckman), include performance guarantees, insurance instruments, and flexible power purchase agreements designed to minimize exposure to financial volatility. The Mekong River Commission's Hydropower Mitigation Guidelines further expand the scope of mitigation by incorporating environmental and social risk management strategies. These include biodiversity offsets, community resettlement planning, sediment control, and cumulative impact assessments. Such multidimensional mitigation approaches align with the broader concept of sustainable hydropower development, ensuring that the risk index encompasses both quantitative and qualitative dimensions of risk control.

2.13 Integrating Expert Input and Adaptive Mitigation

The integration of expert elicitation and participatory modeling has been increasingly used to validate hydropower risk mitigation frameworks. According to Pérez-Rivas et al. (2023), content validity through expert panels ensures that mitigation strategies are not only technically sound but also contextually relevant. This methodological rigor enhances the predictive reliability of the risk index by incorporating localized knowledge and professional judgment. When combined with quantitative verification such as pilot testing Abu Hassan et al. (2006) and Khanal & Chhetri (2024), the resulting model exhibits both construct validity and reliability. Furthermore, iterative pilot testing refines the instrument's usability and alignment with the realities of hydropower project implementation.

2.14 Weighting, Normalization and Hybrid Mitigation Prioritization

Within the methodological structure of index development, weighting and normalization procedures ensure comparability of heterogeneous risk factors. Chen et al. (2022) demonstrated that composite index construction benefits from integrating expert opinions with statistical normalization to balance subjective and objective data inputs. Descriptive statistical summaries (R. Cooksey) and R. W. Cooksey (2020) provide an overview of the distribution of expert ratings, while inferential analyses test the significance of observed relationships. The integration of both descriptive and inferential methods enhances the analytical robustness of hydropower risk evaluations. In practice, weighting can be derived from expert consensus or data-driven methods such as factor analysis and fuzzy reasoning (Li et al., 2023). Such hybrid approaches provide both transparency and replicability in the calculation of the Hydropower Risk Index.

2.15 Dynamic Risk Mitigation in Adaptive Governance

Lastly, the adoption of risk mitigation strategies should be guided by empirical evaluation and adaptive management principles. Yucesan & Kahraman (2019) noted that continuous feedback and monitoring allow for real-time updates to risk-control measures. The Mekong River Commission’s Hydropower Mitigation Guidelines emphasize adaptive planning cycles that integrate hydrological variability, climate change, and socio-economic transitions into risk management frameworks. Similarly, Ojha et al. (2025) stressed that the integration of monitoring data, stakeholder feedback, and post-project evaluation enhances long-term project resilience. Therefore, embedding mitigation strategies within the HRI framework enables decision-makers to move beyond static assessments toward dynamic, iterative risk management approaches that are better aligned with the complexities of hydropower development.

2.16 Composite Indices in Risk and Performance Assessment

Hydropower projects are inherently complex, involving multiple technical, environmental, financial, and social dimensions that create a highly uncertain risk landscape. To address this complexity, composite indices have become a widely accepted approach in both academic research and practical project management. Composite indices consolidate heterogeneous risk indicators into a single, interpretable metric, providing a systematic framework for evaluating project vulnerability (Chakrabartty). In hydropower contexts, this allows project managers and policymakers to translate abstract risks, such as geological instability or regulatory delays, into quantifiable measures, thereby facilitating informed decision-making and prioritization (Kumar et al., 2013).

A key advantage of composite indices is their capacity to integrate data from multiple dimensions into a single, coherent measure. For instance, a single index value can simultaneously reflect financial exposure, technical challenges, environmental sensitivity, and social impacts, which would otherwise require separate assessments. Cross-disciplinary applications demonstrate the versatility of this approach in environmental management and economic policy, composite indices have been employed to rank project performance, guide resource allocation, and evaluate policy outcomes (Mazziotta & Pareto, 2013). The same methodological principles are directly applicable to hydropower projects, where integrating financial, technical, environmental, and social risks is essential to capturing the true project risk profile (Chakrabartty).

The development of a composite index requires a series of key steps, including identifying appropriate indicators, standardizing the data, assigning weights to each factor, combining the scores, and validating the final index. Each stage influences the overall accuracy and interpretability of the index. For example, including indicators that are not closely aligned with the risk construct can produce misleading conclusions, while inadequate weighting can underrepresent critical risks (Chen et al., 2022). Therefore, the construction of the Hydropower Risk Index (HRI) must carefully consider both theoretical frameworks of risk and the practical realities of hydropower implementation, including local environmental conditions, regulatory requirements, and technological limitations (Cherchye et al., 2007).

2.17 Normalization of Indicators

Normalization is a fundamental step in composite index construction, ensuring that indicators measured in different units are comparable. Risk data often vary widely: financial risks are quantified in monetary terms, schedule risks in time delays, Design Risks in reliability scores, and environmental or social risks on qualitative scales (Andreas et al., 2020). Without normalization, aggregation of these indicators would be meaningless, as disparities in scale and unit would bias the index toward indicators with larger numeric ranges. Widely used normalization methods include min–max scaling, z-score standardization, and distance-to-reference techniques (Index methodology). Min–max scaling converts indicator values to a 0–

1 scale, making results easier to interpret, though it is vulnerable to extreme values. In contrast, z-score standardization rescales data using the mean and standard deviation, providing greater statistical reliability for normally distributed variables; however, it can be harder for non-specialists to understand (Venditti & Biomaterials, 2016).

Normalization is not only a technical process but also a value-laden decision. For example, prioritizing environmental risks over financial risks by choosing specific scaling methods can influence investment and policy decisions (Pizzol et al., 2017). In hydropower projects, such decisions are particularly consequential, as both environmental impacts (e.g., river ecosystem disruption) and financial exposures (e.g., cost overruns) have long-term implications for project success. Therefore, transparency in the choice of normalization method is essential to build trust among stakeholders and ensure that the Hydropower Risk Index accurately reflects the relative severity of diverse risks (Andreas et al., 2020).

2.18 Weighting of Indicators

Following normalization, assigning appropriate weights to each indicator is critical for reflecting their relative importance. While equal weighting is straightforward, it fails to capture the differentiated significance of risk factors. In hydropower projects, risks related to geotechnical conditions, financing, and hydrological variability typically carry greater implications than minor administrative or procedural delays (Chen et al., 2022). Consequently, expert-driven or statistically derived weighting schemes are generally preferred.

Weighting can be conducted using expert judgment, analytical hierarchy process (AHP), regression models, or entropy-based statistical methods. Expert judgment allows incorporation of sector-specific knowledge and contextual nuances, particularly in areas with limited data, while statistical methods enhance objectivity and replicability (Kumar et al., 2013; Chakrabartty). However, relying solely on expert opinion may introduce bias, whereas purely statistical methods may overlook critical local insights. A hybrid approach, combining empirical analysis with expert consultation, is recommended for hydropower risk assessment to maintain both methodological rigor and contextual relevance (Mazziotta & Pareto, 2013).

Lessons from sustainability assessment and environmental indices further emphasize the importance of weighting. For instance, the Enviroscore, used to evaluate environmental impacts of products, demonstrates that weighting decisions directly affect comparisons across categories, which can influence stakeholder decisions (Ramos et al., 2022). In the context of hydropower, this underscores the need to carefully balance financial, technical, environmental, and social dimensions within the HRI to reflect the relative importance of each risk type accurately.

2.19 Aggregation of Indicators

Once normalized and weighted, indicators are aggregated to produce the final composite index. Aggregation may be compensatory, where high performance in one dimension can balance lower performance in another, or non-compensatory, where such trade-offs are not permitted in order to emphasize key threshold levels (Cherchye et al., 2007). The choice of aggregation method has significant implications for interpreting hydropower risks. Compensatory methods may underestimate severe risks, such as geological instability, by averaging them with favorable performance in less critical dimensions. Non-compensatory methods, while preserving the significance of severe risks, may overemphasize localized issues, potentially affecting project feasibility (Chakrabartty).

Hybrid aggregation approaches, integrating both compensatory and non-compensatory logic, have proven effective in environmental performance indices and can be applied to hydropower risk assessment (Mazziotta & Pareto, 2013; Pizzol et al., 2017). Such approaches allow critical risks to retain appropriate weight while still considering overall project performance, providing a more nuanced and actionable HRI framework. For example, geological risk may be weighted heavily in non-compensatory logic, while schedule or financial deviations may be partially offset in a compensatory manner.

2.20 Reliability and Validity of Composite Indices

The utility of a composite index depends heavily on its reliability and validity. Reliability assesses whether the index consistently measures the intended construct, while validity ensures that it captures the concept it is designed to reflect (Tavakol & Dennick, 2011). Cronbach’s alpha is a commonly applied method for assessing internal consistency, offering a numerical estimate of how closely the individual items in an index are correlated with one another (Cronbach’s Alpha; SMF Jugessur). A high Cronbach’s alpha indicates that the selected indicators coherently represent the overall risk construct, thereby enhancing the credibility of the HRI.

Sample size is also critical in empirical validation of risk indices. Adequate sample sizes ensure statistical power, reduce estimation bias, and improve generalizability. Bartlett et al. (2001) emphasize careful selection of sample sizes for surveys, while Cochran’s formula provides a practical tool for determining appropriate sample size under different confidence and precision levels (Cochran, 1977). Additionally, construct validity is crucial; an index that focuses solely on financial risks without incorporating environmental, technical, and social factors would fail to provide a comprehensive risk assessment (Chen et al., 2022). Iterative testing, expert feedback, and empirical validation are therefore essential steps to ensure both reliability and validity in constructing the HRI (Chakrabartty).

2.21 Lessons from Cross-Sector Applications

Cross-sector applications of composite indices provide valuable insights for hydropower risk assessment. In solid waste management, indices integrating environmental, economic, and social indicators enhanced operational efficiency and guided policy development (Elsadig et al., 2016). Life cycle assessment studies similarly highlight normalization, weighting, and aggregation as critical challenges, reinforcing the need for methodological transparency and rigor (Andreas et al., 2020; Pizzol et al., 2017).

Applying these lessons to hydropower, the HRI can be designed to quantify risks across multiple dimensions while maintaining interpretability and credibility. By drawing from established methodologies in other sectors, the HRI framework ensures that financial, technical, environmental, and social risks are represented proportionately and consistently. Such a comprehensive index supports evidence-based decision-making, prioritizes risk mitigation strategies, and informs project planning and resource allocation in Nepal’s hydropower sector (Chakrabartty; Chen et al., 2022; Tavakol & Dennick, 2011).

2.22 Integrating HRI into Hydropower Project Management

The practical application of the HRI in hydropower project management involves several steps. First, project-specific risk indicators are identified through expert consultation and historical project analysis. Second, these indicators are normalized and weighted based on relative significance. Third, aggregation produces the overall HRI score, which can be benchmarked against historical performance or international best practices. Finally, results guide mitigation measures, such as reinforcing geological monitoring, optimizing financial planning, or enhancing environmental safeguards. This structured integration ensures that the HRI is not merely an academic exercise but a practical tool for reducing project vulnerability and supporting sustainable hydropower development (Kumar et al., 2013; Chakrabartty).

By integrating rigorous methodology, empirical validation, and insights drawn from cross-sector applications, the HRI provides a robust and practical framework for evaluating risks in hydropower projects in Nepal. It further supports policymakers, engineers, and investors in making well-informed decisions that improve project outcomes, mitigate delays, and reduce both financial and environmental impacts. Ultimately, the HRI represents a step toward systematic and evidence-based risk management in a sector that is central to Nepal's energy security and economic development (Chen et al., 2022; Pizzol et al., 2017).

2.23 Lessons from the Labor Productivity Index (LPI) Model

In the context of Nepal's construction sector, a Labor Productivity Index (LPI) was developed to address the lack of standardized methods for evaluating on-site performance (Maharjan, 2025). This method establishes a solid basis for creating a Hydropower Risk Index (HRI) by illustrating the objective measurement and integration of both qualitative and quantitative factors into a unified benchmarking framework.

The LPI was formulated by identifying twelve key productivity factors such as material delivery, worker skill, supervision, and planning quality through expert validation. Each factor was assigned a weight based on its impact, and survey data were normalized on a 0–100 scale. The LPI was calculated using a weighted summation formula:

$$\text{LPI} = W_i \times N_i$$

Where W_i is the weight and N_i is the normalized score of the i^{th} factor. This method ensured comparability between projects and allowed for benchmarking using a five-star performance rating system.

The same process can be applied to the HRI. Risk categories such as safety, time, cost, and environmental risks can be identified, weighted, and scored using similar stakeholder input and statistical methods. The structured index model highlights the value of quantifying complex field data into actionable metrics, enabling better decision-making, early warning, and continuous improvement (Maharjan, 2025).

Thus, the LPI framework demonstrates how structured, expert-informed indices can enhance objectivity, which is crucial for developing a HRI in Nepal's construction risk landscape.

2.24 Challenges and Research Gaps

Although research on risk identification and management within hydropower and construction projects has increased significantly, a number of important challenges still remain unresolved. One of the most notable issues is the lack of reliable and accessible data, especially in developing countries where centralized risk information systems are scarce (Abd El-Karim et al., 2017; Chileshe & Boadua Yirenkyi-Fianko, 2012). As a result, many studies continue to depend on expert opinions and subjective assessments, which can limit objectivity and reproducibility (Goji Tipili et al.; Rauzana, 2016).

Another major limitation is the static nature of many existing risk assessment models, which often fail to reflect the dynamic and evolving character of risks throughout the project lifecycle (Gunasekaran et al., 2014; Rezakhani). These models lack the flexibility needed to adapt to changing project conditions and stakeholder environments, particularly in large-scale infrastructure projects like hydropower developments.

Moreover, although the role of digital technologies in managing construction risks is gaining growing recognition, only a limited number of studies have incorporated tools like Building Information Modeling (BIM), artificial intelligence (AI), or predictive analytics within their risk assessment frameworks (Maharjan, 2025; Shaktawat & Vadhera, 2021). This presents a valuable research opportunity to explore how such technologies could enhance real-time monitoring and updates of a Hydropower Risk Index (HRI).

The literature also tends to focus on conventional project delivery mechanisms, with limited attention to alternative approaches such as design-build or public-private partnerships (PPP) (Agarwal & Kansal, 2020; Bhatt & Joshi, 2024). hydropower projects. These models introduce distinct contractual and coordination risks that have not yet been sufficiently examined in existing research, especially within hydropower project contexts.

Furthermore, in the specific case of Nepal, challenges such as labor productivity, stakeholder engagement, and institutional inefficiencies remain under-investigated, despite their significant influence on project outcomes (Maharjan, 2025 ; Chaudhary, 2024; Tripathi et al., 2017). These gaps point to the necessity for a dynamic, localized, and technology-supported risk index that can address both conventional and emerging risk dimensions in hydropower development.

2.25 Summary of Literature Review

The reviewed literature underscores the urgent need for a structured and localized approach to risk identification and assessment in hydropower projects, particularly in contexts like Nepal where complex socio-political, economic, and environmental conditions prevail. Hydropower development is exposed to a broad spectrum of risks, ranging from financial and regulatory uncertainties to inefficiencies in labor and weaknesses in stakeholder coordination (Abd El-Karim et al., 2017; Gunasekaran et al., 2014; Chileshe & Boadua Yirenkyi-Fianko, 2012). If these risks are not properly identified, evaluated, and managed, they can result in significant project delays, cost overruns, and reduced overall project performance (Rauzana, 2016 ; Tessema et al., 2022).

The development of a Hydropower Risk Index (HRI) emerges as a promising solution, offering a quantitative and multidimensional framework to evaluate and prioritize risks. Drawing inspiration from tools like the Labor Productivity Index (LPI), Maharjan (2025), the HRI can incorporate expert-validated factors, statistical weighting, and normalized scoring to provide actionable insights for stakeholders.

Despite progress in global and regional risk assessment practices, several gaps remain, including limited use of adaptive and digital technologies, reliance on subjective assessments, and inadequate exploration of alternative delivery models like PPP (Rezakhani; Agarwal & Kansal, 2020). Addressing these challenges through an empirically grounded, flexible, and context-sensitive HRI will significantly enhance project planning, execution, and sustainability in Nepal's hydropower sector.

In essence, the literature supports a transition from fragmented risk identification efforts toward a holistic, data-driven index that empowers stakeholders to mitigate risks effectively across the hydropower project lifecycle.

CHAPTER 3: METHODOLOGY

3.1 Research Approach

This study employs a mixed quantitative and qualitative approach to investigate risk management practices in hydropower projects and to formulate a Hydropower Risk Index (HRI). Primary data were gathered through a structured questionnaire survey administered to hydropower professionals. The risk factors were organized into ten thematic categories, initially identified from existing literature and subsequently refined through expert consultations and Key Informant Interviews (KII). A cross-sectional research design was adopted, capturing data at a single point in time, with purposive sampling used to ensure responses from experienced practitioners in the sector.

The data were analyzed using both descriptive and inferential statistical methods, including frequency distributions, mean score analysis, and Chi-square tests. In addition, an index-based modeling approach involving weighting, normalization, and aggregation techniques was applied to develop the HRI. The reliability and validity of the dataset were assessed through Cronbach’s Alpha, Pearson correlation analysis, and sensitivity testing. Final validation of findings was carried out through expert review and Key Informant Interviews (KII). Overall, the methodology combines statistical analysis with expert judgment to establish a robust, systematic, and context-sensitive framework for evaluating and managing risks in Nepal’s hydropower sector.

3.2 Research Design

A research design functions as the basic blueprint that guides the overall execution of a study. It specifies the methods used to answer research questions by detailing how data will be collected, measured, and analyzed. Rooted in the study’s theoretical framework, it focuses on identifying key variables, which in turn support the formulation of the conceptual framework presented in Figure 3.1.

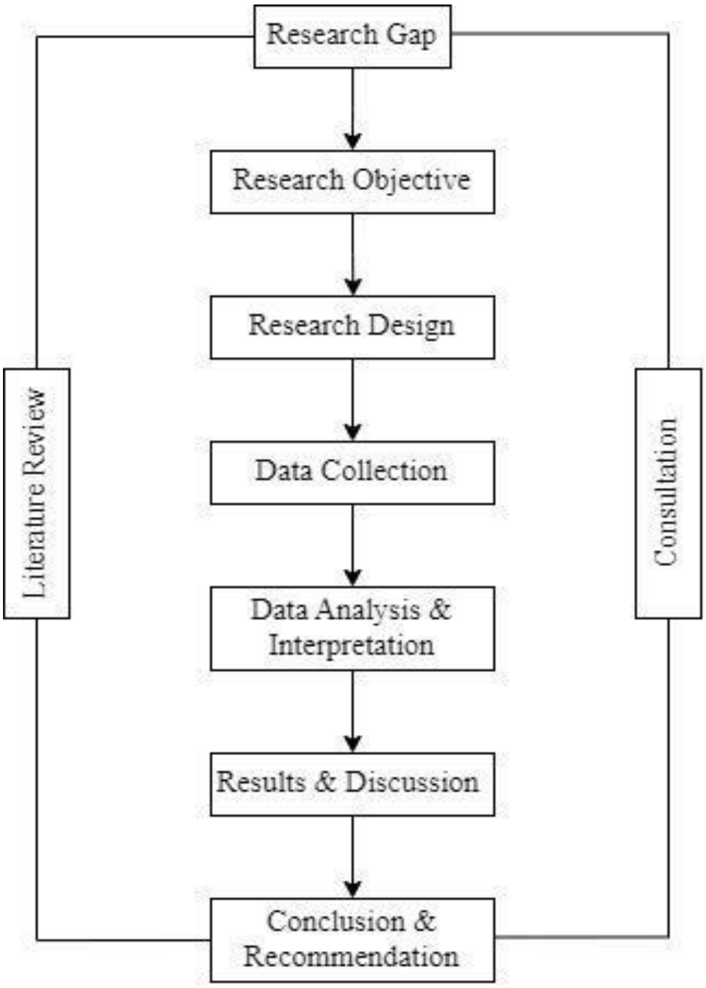


Figure 3. 1 Research Design

3.3 Research Framework

The research framework followed in this study is presented in Figure 3.2. The study began with the distribution of a structured questionnaire to professionals in the hydropower sector, which was administered electronically using Kobo Toolbox. The responses obtained were then analyzed using both descriptive and inferential statistical techniques. Risk factors were organized into ten broad categories and evaluated in terms of their perceived severity and probability. Expert-based weighting and normalization techniques were subsequently applied to each factor before aggregating them into a unified Hydropower Risk Index (HRI). The stability and reliability of the index were further examined through sensitivity and correlation analyses. Expert consultations and Key Informant Interviews (KII) were carried out as a final step to validate the outcomes of the study.

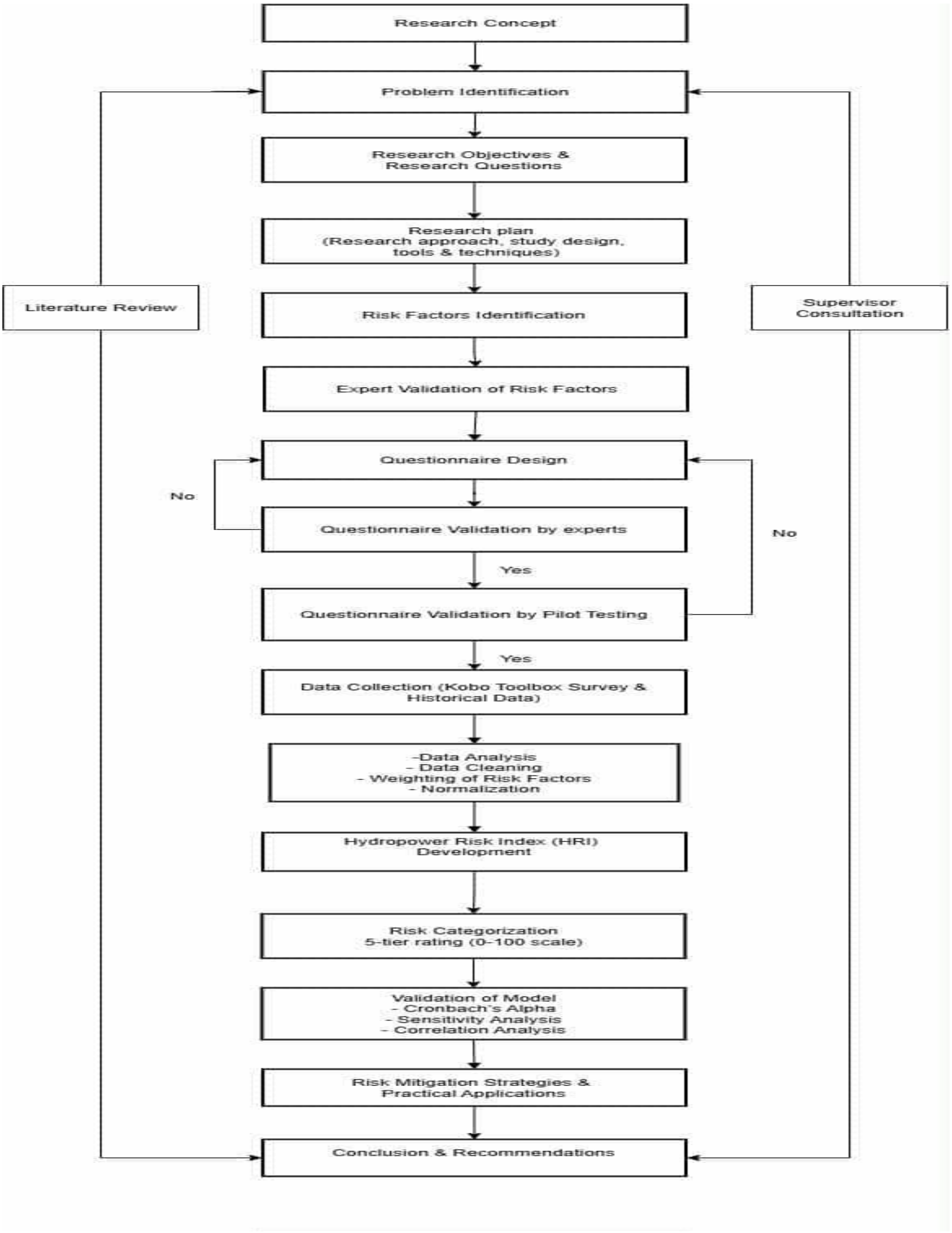


Figure 3. 2 Research Framework

3.4 Study Area

This study is geographically centered on the Kathmandu Valley, where all data collection activities were conducted. Given that the valley accommodates a dense concentration of hydropower sector professionals spanning project managers, contractors, consultants, engineers and government regulatory bodies, it was deemed a suitable and representative setting for the intended study population.

3.5 Population Sampling, Sample Design and Sample Size

The study focused on professionals who are currently engaged in active roles within the hydropower sector in Nepal. Recognizing that professionals based in the Kathmandu Valley are frequently engaged with hydropower projects across varying locations throughout the country, the survey was administered without restrictions on the respondents' current project postings. The population of hydropower professionals concentrated within the valley was used as the reference figure for determining the required sample size.

For the purpose of Key Informant Interviews (KII), consultations were held with six experienced hydropower experts to validate the survey instrument and refine the list of risk factors before the questionnaire was formally deployed.

The minimum number of survey respondents was determined using Cochran's formula, as presented in Equation 3.1.

$n_0 = (z^2 \times p \times q) / e^2$ ……………………………………………… Equation 3.1

- n represents the required sample size
- z denotes the standard normal value associated with a 90% confidence level, which is 1.645
- p is the assumed proportion of the population, taken as 0.5
- q is the complement of p, calculated as $1 - p = 0.5$
- e refers to the permissible margin of error, set at 10%

The computation produced a minimum required sample size of 68. The survey was ultimately completed by 102 professionals, surpassing the minimum threshold and providing broad representation across the relevant stakeholder groups.

3.5.1 Sampling Method

A purposive sampling technique was used in this study. Survey questionnaires were deliberately circulated among professionals who possessed direct and relevant experience in hydropower project planning, execution, and management. Respondents were intentionally selected from specific stakeholder categories including project owners, contractors, consultants and engineers on the basis of their professional expertise, hydropower sector involvement and depth of knowledge in Nepal's hydropower sector. Given the specialized and technical nature of risk assessment in hydropower projects, it was essential that only those with sufficient hands-on exposure to project risks and their consequences participated in the study. This targeted selection process ensured that the data collected accurately reflected the ground realities of hydropower project implementation in Nepal, thereby strengthening the reliability and contextual relevance of the developed Hydropower Risk Index (HRI).

3.6 Methods of Data Collection

3.6.1 Primary Data Collection

Primary data is the firsthand information collected directly by the researcher specifically for the objectives of the study. In this research, such data were obtained through a structured questionnaire survey. The instrument was developed to assess risk factors spanning ten identified categories encompassing design, management and coordination, resource, financial, economic, political, environmental, social, contractual and operational risks. Respondents evaluated each factor using a three-point Likert scale, in which a score of 1 represented low risk, 2 represented moderate risk, and 3 indicated high risk. Ethical considerations were carefully observed throughout the process, with anonymity and voluntary participation guaranteed to reduce the likelihood of response bias. The questionnaire was built using the Kobo Toolbox platform and underwent pilot testing with ten respondents, following which minor adjustments were made to improve clarity. The refined version was subsequently distributed electronically to professionals across multiple hydropower organizations. The complete questionnaire is provided in APPENDIX 1, while the profile of respondents is documented in APPENDIX 2. Key Informant Interviews (KII) were conducted with six experienced hydropower domain experts to cross-verify and validate the findings of the study.

3.6.2 Secondary Data Collection

An extensive review of existing literature was undertaken drawing upon a range of sources including peer-reviewed academic articles, books and credible online resources. The review aimed to consolidate current knowledge on risk management practices within hydropower and broader infrastructure sectors, examine established frameworks for risk identification and evaluation, and lay a solid theoretical groundwork for the present study. The results obtained from this review were crucial in determining the choice of risk factors, designing the survey instrument, and informing the methodological framework used in the development of the HRI.

3.7 Data Analysis

The quantitative data collected via the structured questionnaire survey were organized, processed, and analyzed in a systematic manner using Microsoft Excel and SPSS software. To summarize the responses gathered for each risk factor, descriptive statistical measures encompassing frequency distributions, mean scores and standard deviations were computed. Relative weights were subsequently assigned to individual risk categories in order to capture their comparative significance within the overall risk landscape of hydropower projects. Normalization was then applied to standardize all scores onto a uniform scale of 0 to 100, ensuring comparability across different risk categories. The weighted and normalized values were thereafter consolidated through aggregation to derive the final Hydropower Risk Index (HRI).

To examine significant association between observed differences in respondent awareness and perception of risk management practices, and also between risk factors and risk levels, a Chi-Square test was performed. Cronbach's Alpha was used to assess the internal consistency and reliability of the survey instrument, verifying that the selected risk indicators within the index are well aligned and coherent. Furthermore, the validity and robustness of the developed HRI were verified through sensitivity analysis and Pearson correlation testing, ensuring that the index accurately and consistently captured the relative impact of identified risk factors across Nepal's hydropower sector.

3.8 Reliability of Research

3.8.1 Reliability Statistics

Cronbach's Alpha (α) was used to assess the reliability and internal consistency of the questionnaire data. This widely accepted statistical indicator evaluates whether items intended to measure the same underlying construct yield consistent responses (Zahreen et al., 2018). The coefficient ranges from 0 to 1, where higher values indicate greater internal consistency. The interpretation scale is presented in Table 3.1 below.

The Cronbach's Alpha coefficient is calculated using the following formula:

$$\alpha = [K / (K - 1)] \times [1 - (\Sigma\sigma^2{}_{\mathrm{K}} / \Sigma\sigma^2 total)] \text{...........Equation 3.2}$$

Where,

K denotes the total number of items,

$\sum\sigma^2_k$ represents the sum of the variances of individual items, and

$\sum\sigma^2_{total}$ denotes the variance of the total scores obtained from respondents across all items.

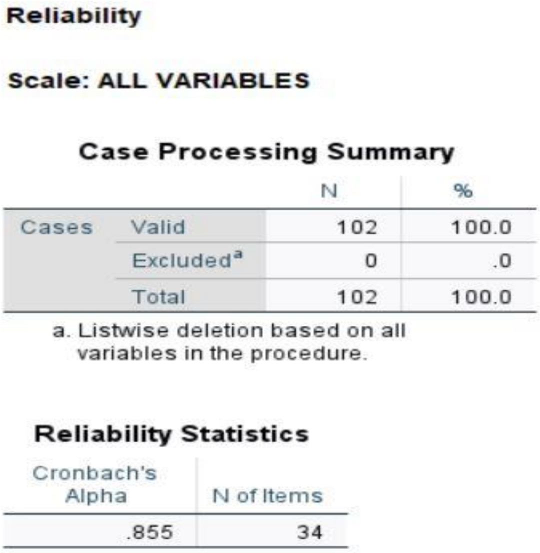
Table 3. 1 Interpretation of Cronbach's Alpha Values

Cronbach's alpha (α)	**Internal Consistency**
0.9 -1	Excellent
0.8 – 0.89	Good
0.7 – 0.79	Acceptable
0.6 – 0.69	Questionable
0.5 – 0.59	Poor
$\alpha < 0.49$	Unacceptable

Source: Adapted from Zahreen, K., Arof, M., Ismail, S., and Saleh, A. L. (2018), *Contractor's Performance Appraisal System in the Malaysian Construction Industry: Current Practice, Perception and Understanding*, published in the *International Journal of Engineering & Technology*, Vol. 7, Issue 3.

Reliability Checking of the Data

After an adequate number of survey responses had been collected through the Kobo Toolbox platform, the instrument's reliability was assessed. In the initial analysis, 102 valid responses from the target sample were considered. The Cronbach's Alpha value obtained was 0.855, which is close to 1 and indicates strong internal consistency, thereby confirming that the questionnaire is a reliable tool for measuring hydropower risk factors.



Reliability

Scale: ALL VARIABLES

Case Processing Summary

		N	%
Cases	Valid	102	100.0
	Excluded[a]	0	.0
	Total	102	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.855	34

Figure 3. 3 Reliability Statistics Value

The outcome confirms that the survey instrument used to assess hydropower risk factors was highly reliable, providing a dependable foundation for further data analysis and for constructing the Hydropower Risk Index (HRI).

3.9 Research Matrix

Table 3.2 presents the research matrix developed for this study.

Table 3. 2 Research Matrix

Objectives	Research Questions	Data Required	Methods / Tools	Expected Output
To identify and evaluate critical risk factors influencing the performance of hydropower projects.	What are the critical risk factors affecting the performance and outcomes of hydropower projects?	- Literature-derived risk categories - Risk factor ratings from hydropower professionals	- Questionnaire survey - Descriptive statistics (frequency distribution, mean, standard deviation)	A prioritized inventory of risk factors and their relative significance across ten identified categories of hydropower project risk
To develop a structured and context-specific Hydropower Risk Index (HRI) that quantifies the relative impact of identified risk factors.	How can a Hydropower Risk Index (HRI) be developed to quantify and prioritize these risks for effective management?	- Survey-derived Likert scale ratings - Expert-assigned factor weights - Normalized scores	- Factor weighting and normalization - Weighted aggregation - Cronbach's Alpha reliability test - Chi-Square test - Sensitivity analysis - Pearson correlation analysis	A validated, quantitative HRI (0–100 scale) with a five-level risk rating system, offering a systematic and replicable framework for risk prioritization in Nepal's hydropower projects

To recommend appropriate risk mitigation measures grounded in the analysis of the developed risk index.	What risk mitigation measures can be recommended based on the analysis of the developed Hydropower Risk Index (HRI)?	- Qualitative feedback from survey respondents - KII findings from domain experts - Literature on mitigation practices	- Descriptive analysis - Literature-based synthesis - Key Informant Interviews (KII)	Targeted, evidence-based mitigation recommendations aligned with the priority risk levels established by the HRI, supporting informed decision-making for hydropower project stakeholders in Nepal

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Identification and evaluation of critical risk factors influencing the performance of hydropower projects

The first objective of this study was to determine and assess the key risk factors affecting the performance of hydropower projects in Nepal. To achieve this, a preliminary list of 41 risk factors was compiled through a comprehensive literature review. These factors were then subjected to an expert validation process involving six senior hydropower professionals to ensure their relevance to the specific technical, financial, and environmental context of Nepal. Finally, a structured questionnaire survey was conducted with 102 hydropower professionals to assess the perceived impact and frequency of these factors.

4.1.1 Expert Validation Analysis

From the expert validation survey, the consensus on the relevance of the 41 identified factors was determined as follows:

- Factors validated (≥ 4/6 agreement): 82.9% (34 factors)
- Factors rejected (< 4/6 agreement): 17.1% (7 factors)
- Total factors retained for primary survey: 34 factors

A total of seven factors were rejected as they failed to meet the validation threshold, being perceived by the experts as less critical or as standard operational variances. Table 4.1 presents a detailed overview of the factors that were excluded from the analysis.

Table 4. 1 Details of risk factors rejected by experts

S.No.	Risk Factor	Expert Agreement	Reason for Rejection
1	Frequent design revisions during construction	2/6	Considered common operational variance
2	Ineffective inter-agency and cross-border coordination	2/6	Less relevant for national-scale projects
3	Inefficient procurement of spare parts and consumables	1/6	Low perceived impact on construction
4	Inadequate allocation/utilization	1/6	Viewed as internal management

	of contingency budgets		task
5	Political instability and frequent leadership changes	2/6	Perceived as a macro-environment constant
6	Poor implementation of environmental mitigation	1/6	Rated as a low-impact factor for performance
7	Inadequate emergency and disaster response planning	2/6	Not viewed as a critical pre-performance risk

The 34 validated factors were retained because they represent critical technical, financial and managerial uncertainties that directly impact project cost, schedule and quality in Nepal. These factors were grouped into ten major risk categories. The justification for selecting these categories is explained in Table 4.2.

Table 4. 2 Details of the 34 validated risk factors and reasons for acceptance

S.No.	Risk Factor	Expert Agreement	Reason for Acceptance
1	Incomplete geological & hydrological investigation	4/6	High literature support and expert consensus on technical uncertainty.
2	Poor dam design or tunnel alignment	5/6	Critical impact on safety and performance in Himalayan terrain.
3	Difficult topography & terrain	4/6	Core geological constraint directly affecting design feasibility in Nepal.
4	Lack of adaptability to remote site conditions	6/6	Unanimous agreement on its practical importance for remote project logistics.
5	Poor coordination between parties	5/6	Essential for addressing the technical complexity of hydropower management.
6	Inexperience in managing hydropower complexity	4/6	Recognized as a critical managerial variable affecting project quality.
7	Ineffective stakeholder communication	6/6	Unanimous validation due to its high impact on project

			transparency.
8	Remote access leads to supply delays	4/6	Validated for its direct influence on project schedule and timelines.
9	Skilled hydropower workforce shortages	5/6	Critical resource risk identified in local and global construction studies.
10	Equipment inaccessibility/unsuitability for terrain	4/6	Contextually relevant to Nepal’s mountainous and difficult geography.
11	Reliability and Creditworthiness of the Offtaker	4/6	Key financial risk determining project viability and cash flow.
12	Grid Availability and Dispatch Risk	6/6	Unanimous expert endorsement as a critical operational and financial threat.
13	Delay in financial closure	5/6	Significant literature backing as a major cause of initial project delays.
14	Difficulty in securing private sector investment	4/6	Validated for its role in determining project funding and sustainability.
15	Underestimation of tunnel/powerhouse costs	6/6	Unanimous agreement on its high probability and severe cost impact.
16	Cost escalation due to imported machinery	4/6	Critical economic factor due to Nepal's high dependency on imports.
17	Foreign exchange risks for loan repayments	5/6	Validated based on the potential impact of currency volatility on project debt.
18	Inflation during long project durations	6/6	Unanimous recognition as a high-frequency risk in long-term infrastructure.
19	Unstable regulatory framework	4/6	Validated for its high impact on project planning and execution stability.
20	Bureaucratic delays in permits	4/6	A recurring institutional

			bottleneck identified by industry experts.
21	Local-level opposition or interference	6/6	Unanimous agreement on its severe impact on project implementation.
22	High environmental sensitivity of project area	5/6	Crucial for compliance in fragile Himalayan ecological zones.
23	Landslides, GLOFs, monsoon floods	4/6	Contextually essential due to Nepal’s vulnerability to natural hazards.
24	Delays due to EIAs and compliance	5/6	Recognized as a significant procedural barrier in hydropower development.
25	Land acquisition disputes	4/6	Major social risk documented to cause long-term project disruptions.
26	Inadequate compensation or resettlement	6/6	Unanimous validation as a critical determinant of community acceptance.
27	Cultural/indigenous rights violations	4/6	Validated for its importance in meeting international safeguard standards.
28	Protest and local strikes	5/6	High consensus on its frequent occurrence and impact on site progress.
29	Ambiguous risk-sharing in BOOT contracts	6/6	Unanimous endorsement for its legal and contractual significance.
30	Claims/disputes over design responsibility	4/6	Validated to address common conflicts in complex engineering contracts.
31	International arbitration complexities	5/6	Crucial for projects involving foreign investors and stakeholders.
32	Delays in grid connection	6/6	Unanimous recognition as a primary threat to timely commissioning.

33	Poor hydrological prediction accuracy	4/6	Validated for its critical role in estimating generation capacity.
34	O&M challenges post-construction	5/6	Necessary for assessing the long-term sustainability of a project's operation.

4.1.2 Awareness and Experience of Risk Management in Hydropower Projects

The level of awareness and experience regarding risk management in hydropower projects was assessed using the Chi-square (χ^2) goodness-of-fit test. This statistical method is used to examine whether the observed pattern of responses shows a significant deviation from a uniform (equal) distribution.

Table 4. 3 Awareness and Experience of Risk Management in Hydropower Projects

S. No.	Survey Question	Yes	No	Total
1	Have you heard about risk management practices in hydropower projects?	89	13	102
2	Have you ever received training/workshops/seminars on risk management?	54	48	102
3	Are you aware that poor risk management contributes to project delays and budget overruns?	94	8	102
4	Do you think structured risk assessment improves hydropower project performance?	97	5	102
5	Do you think developing a Hydropower Risk Index (HRI) will improve project performance?	96	6	102
6	Have you been part of a project where risk mitigation measures were applied?	42	60	102
	Total	**472**	**140**	**612**

Table 4. 4 Observed and Expected Frequencies

Category	Observed (O)	Expected (E)	(O − E)	(O − E)²	(O − E)² / E
Yes	472	306	166	27,556	90.05
No	140	306	-166	27,556	90.05
Total	**612**	**612**	**0**	**55112**	**180.10**

Mathematical Calculation

Expected frequency:

$$E = \frac{Total}{2} = \frac{612}{2} = 306$$

Chi-square formula:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Substituting values:

$$\chi^2 = \frac{(472-306)^2}{306} + \frac{(140-306)^2}{306}$$
$$= \frac{166^2}{306} + \frac{(-166)^2}{306} = \frac{27556}{306} + \frac{27556}{306} = 180.10$$

Result and Interpretation

The calculated value is:

$$\chi^2 = 180.10, \quad df = 1$$

At the 0.05 significance level, the critical χ^2 value is 3.84. Because the computed χ^2 value substantially exceeds this threshold, the null hypothesis is rejected.

This result indicates a highly significant statistical difference ($p < 0.001$) between the observed and expected frequencies. It suggests that respondents predominantly selected “Yes,” indicating a strong overall awareness and favorable perception of risk management practices in hydropower projects.

4.2 Development of structured and context-specific Hydropower Risk Index (HRI) that quantifies the relative impact of identified risk factors

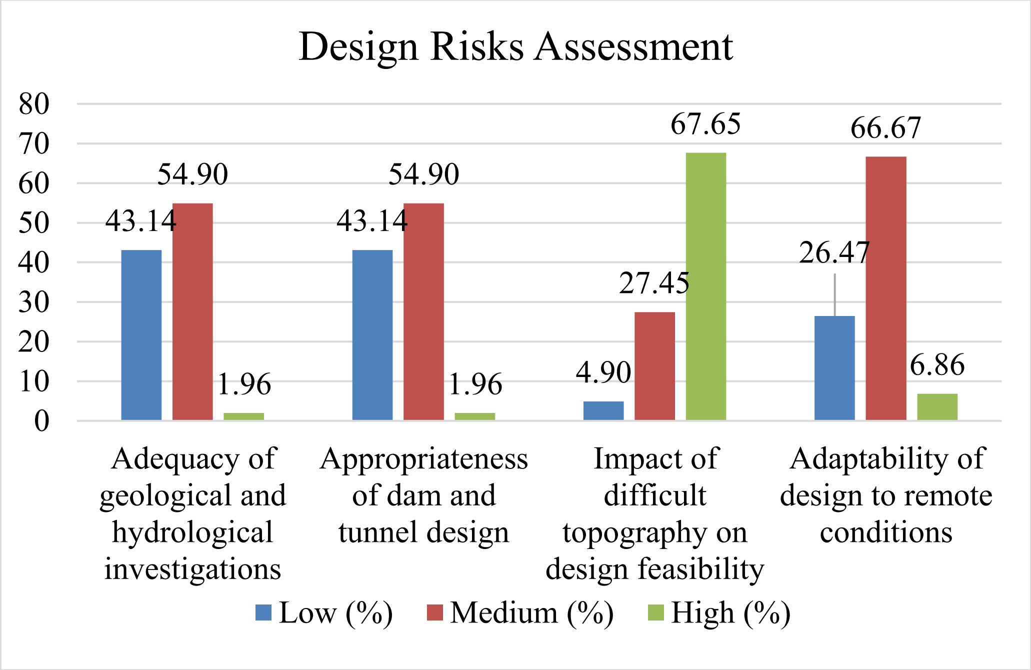
The second objective of this study was to develop a structured and context-specific Hydropower Risk Index (HRI) to quantify and prioritize the risks identified in Objective 1. This was achieved through a multi-stage process involving Likert-scale assessment by hydropower professionals, factor weighting, statistical normalization and rigorous model validation.

4.2.1 Risk Factor Assessment

The risk factors influencing hydropower projects were assessed using a structured questionnaire survey conducted among hydropower professionals. Each risk factor was assessed by respondents using a three-point Likert scale, where Low was assigned a value of 1, Medium 2, and High 3. The responses were then systematically compiled and analysed to evaluate the relative significance and impact of each risk factor. In addition, a chi-square test along with p-values was applied to examine statistically significant associations between the risk factors and their corresponding risk levels. The detailed results are presented in APPENDIX 3. The mean score of each risk factor was calculated to represent its perceived impact level.

A. Design Risks

Design-related risks were assessed in terms of adequacy of investigations, appropriateness of design decisions, adaptability to terrain, and design suitability for remote locations.



Calculated $\chi^2 = 211.7 \gg 12.59$, p-value < 0.001.
So, statistically significant.

Figure 4. 1 Design Risks Assessment

Figure 4.1 illustrates how respondents perceive the degree of risk linked to design-related factors in hydropower projects. The results show that 43.14% of respondents rated the adequacy of geological and hydrological investigations as having a low risk, 54.90% as medium risk, and 1.90% as high risk, indicating moderate concern in this area.

For the appropriateness of dam and tunnel design, 43.14% of respondents rated it as low risk, 54.90% as medium risk, and another 1.90% as high risk, suggesting a moderate concern regarding design adequacy.

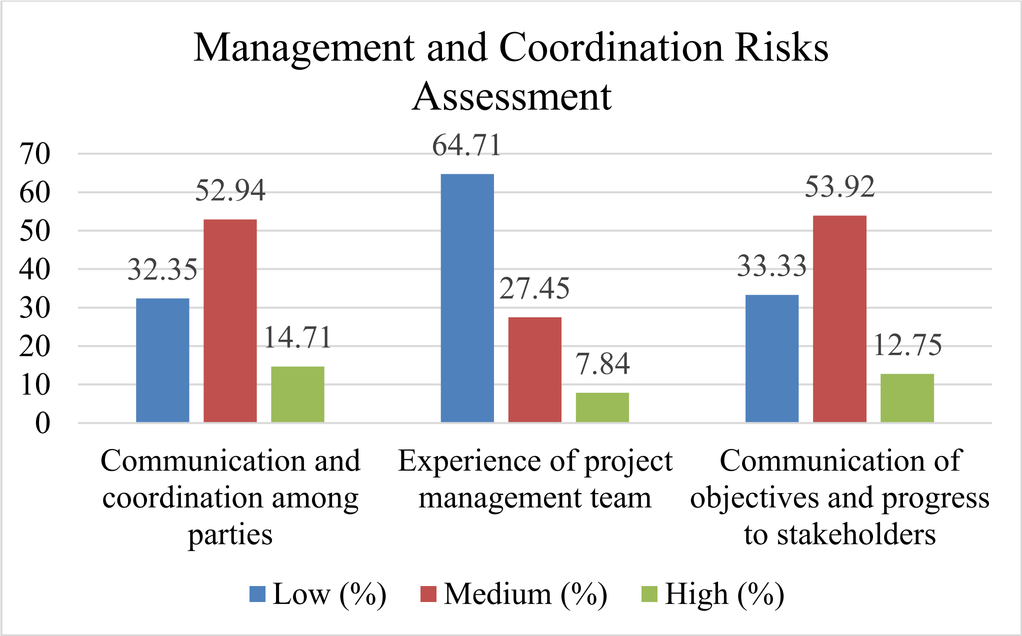
Similarly, regarding the impact of difficult topography on design feasibility, 4.90% rated it as low risk, 27.45% as medium risk, and 67.65% as high risk, showing that terrain-related challenges are viewed as a significant source of risk in hydropower development.

For the adaptability of design to remote conditions, 26.47% of respondents considered it low, 66.67% medium, and 6.86% high risk, indicating that site remoteness and accessibility issues are moderate concerns in project design.

Overall, the findings suggest that while most respondents view geological and hydrological investigations, design adequacy and adaptability of designs to remote conditions as moderately risky, they express greater concern about topographical challenges, which is perceived as critical factor affecting the feasibility and performance of hydropower projects.

B. Management and Coordination Risks

This category focused on communication systems, management experience, and stakeholder coordination.



Calculated $\chi^2 = 33.22 \gg 9.49$, p-value < 0.001. So, statistically significant.

Figure 4. 2 Management and Coordination Risks Assessment

Figure 4.2 presents respondents' perceptions of the level of risk associated with management and coordination factors in hydropower projects. The results show that 32.35% of respondents rated communication and coordination among parties as having a low risk, 52.94% as medium risk, and 14.71% as high risk, indicating that while coordination issues are moderately concerning, they are generally perceived as being managed effectively.

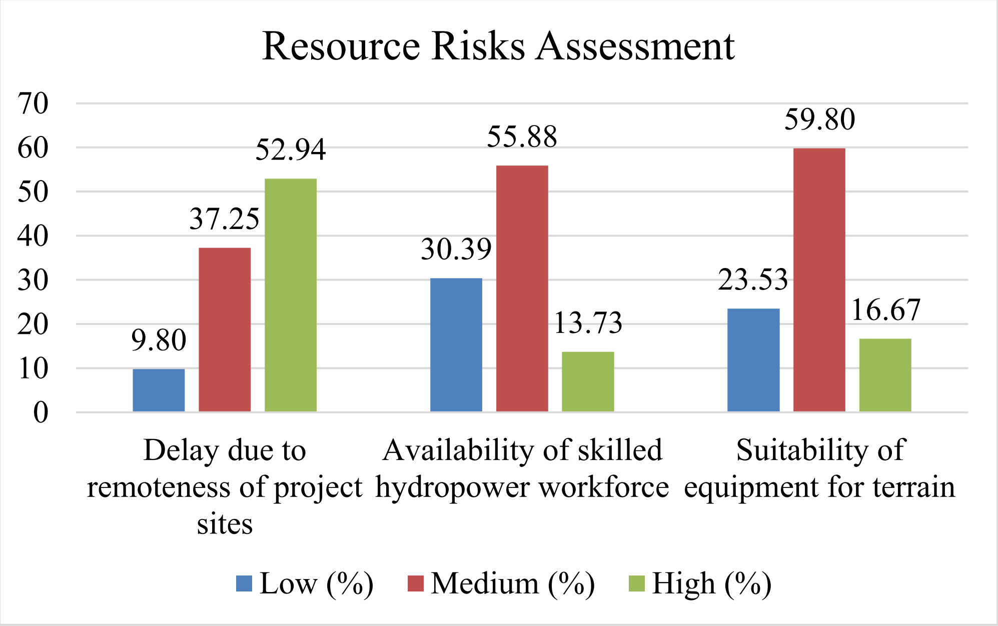
Regarding the experience of the project management team, 64.71% of respondents rated it as low risk, 27.45% as medium risk, and another 7.84% as high risk, suggesting a low perception about the adequacy of managerial experience in project execution.

Similarly, for communication of objectives and progress to stakeholders, 33.33% rated it as low risk, 53.92% as medium risk, and 12.75% as high risk, highlighting that ineffective communication with stakeholders is viewed as a moderate risk factor that can influence project transparency and decision-making.

Overall, the findings indicate that while coordination among project parties and stakeholder communication are perceived as moderately risky, respondents expressed low concern regarding the adequacy of management experience. These aspects are viewed as essential for maintaining project transparency, effective decision-making, and minimizing operational risks in hydropower project execution.

C. Resource Risks

Respondents widely recognized resource-related risks as significant challenges in hydropower development. The remoteness of project sites, limited availability of skilled labor, and unsuitability of construction equipment for mountainous terrain were all perceived as medium to high risk factors.



Calculated $\chi^2 = 60.36 \gg 9.49$, p-value < 0.001. So, statistically significant.

Figure 4. 3 Resource Risks Assessment

Figure 4.3 illustrates how respondents perceive the degree of risk linked to resource-related factors in hydropower projects. The results show that 9.80% of respondents rated the delay due to remoteness of project sites as low risk, 37.25% as medium risk, and 52.94% as high risk, suggesting that while remoteness is recognized as a challenge, it is generally perceived as high risk factor.

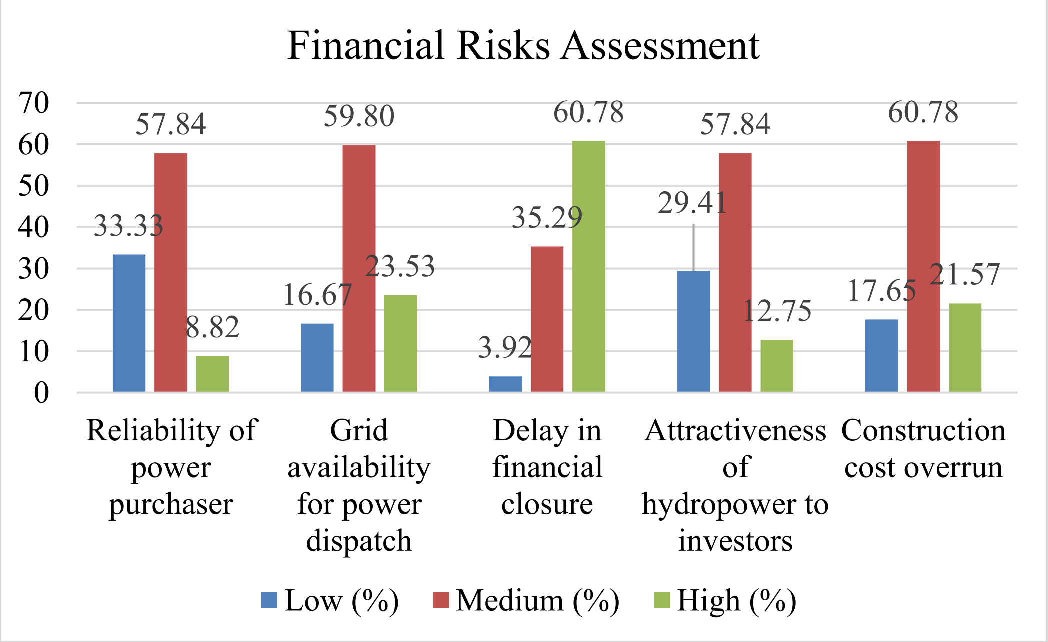
For the availability of a skilled hydropower workforce, 30.39% of respondents rated it as low risk, 55.88% as medium risk, and another 13.73% as high risk, indicating that labor availability and expertise are seen as moderate constraints affecting project implementation.

Similarly, in terms of the suitability of equipment for challenging terrain, 23.53% rated it as low risk, 59.80% as medium risk, and 16.67% as high risk, reflecting a moderate concern regarding the adequacy and adaptability of equipment in difficult geographical conditions.

Overall, the findings indicate that while delays due to project remoteness are largely perceived as high risk, respondents expressed moderate concern regarding the availability of skilled personnel and the suitability of equipment, both of which are considered important factors for ensuring effective implementation of hydropower projects in Nepal's challenging terrains.

D. Financial Risks

Financial risk factors were consistently rated among the most critical. Respondents emphasized concerns over off-taker reliability, grid availability, attractiveness of hydropower to investors, delays in financial closure and cost overruns, which directly influence project cash flow and progress.



Calculated $\chi^2 = 135.26 \gg 15.51$, p-value < 0.001. So, statistically significant.

Figure 4. 4 Financial Risks Assessment

Figure 4.4 illustrates how respondents perceive the degree of financial risk in hydropower projects. The results show that 33.33% of respondents rated the reliability of the power purchaser as low risk, 57.84% as medium risk, and 8.82% as high risk, indicating that most respondents have moderate confidence in power purchasers' reliability.

Regarding grid availability for power dispatch, 16.67% of respondents perceived it as low risk, 59.80% as medium risk, and 23.53% as high risk, reflecting a moderate view over grid connectivity and transmission reliability.

In the case of delay in financial closure, 3.92% rated it as low risk, 35.29% as medium risk, and 60.78% as high risk, suggesting that securing timely financial arrangements is a significant concern in hydropower development.

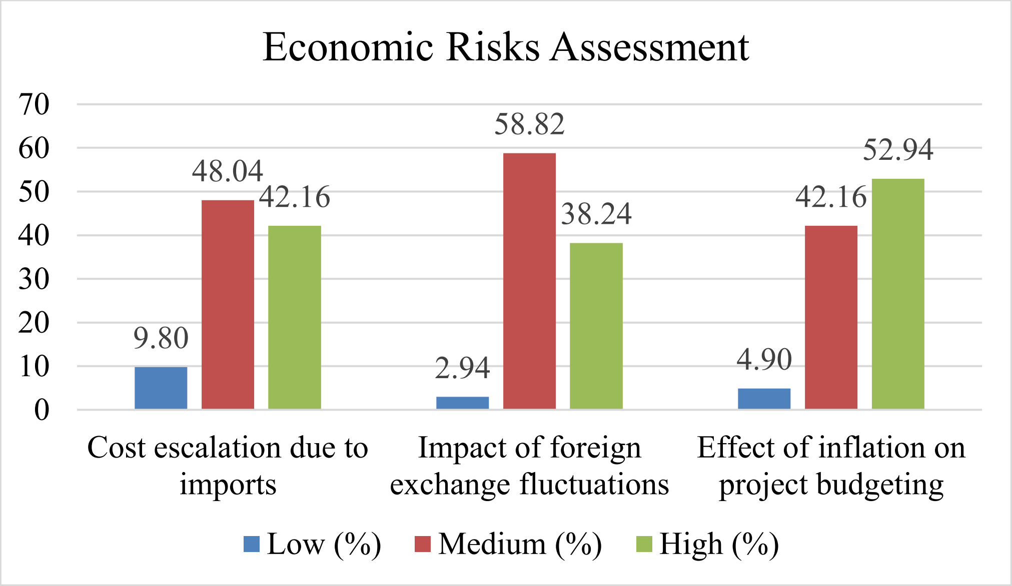
Similarly, for the attractiveness of hydropower to investors, 29.41% considered it low risk, 57.84% medium risk, and 12.75% high risk, showing that investor confidence remains a moderate issue affecting project financing and progress.

Lastly, construction cost overrun was viewed as a major challenge, with 17.65% rating it low, 60.78% medium, and 21.57% high risk indicating moderate concern among respondents about cost escalation during project implementation.

Overall, the findings indicate that while financial factors such as purchaser reliability, grid availability, investor attractiveness and construction cost overruns are considered moderate risks, respondents expressed higher concern regarding delay in financial closure, which is critical for ensuring financial viability and timely completion of hydropower projects.

E. Economic Risks

Economic factors such as cost escalation due to imported machinery, exchange rate fluctuations, and inflation were considered moderate to high risks by most respondents.



Calculated $\chi^2 = 16.03 > 9.49$, p-value < 0.01.
So, statistically significant.

Figure 4. 5 Economic Risks Assessment

Figure 4.5 illustrates how respondents perceive the degree of risk linked to economic factors in hydropower projects. The results show that 9.80% of respondents rated the risk of cost escalation due to imports as low, 48.04% as medium, and 42.16% as high, suggesting that while import-related costs are a concern, most respondents view the associated risk as moderate.

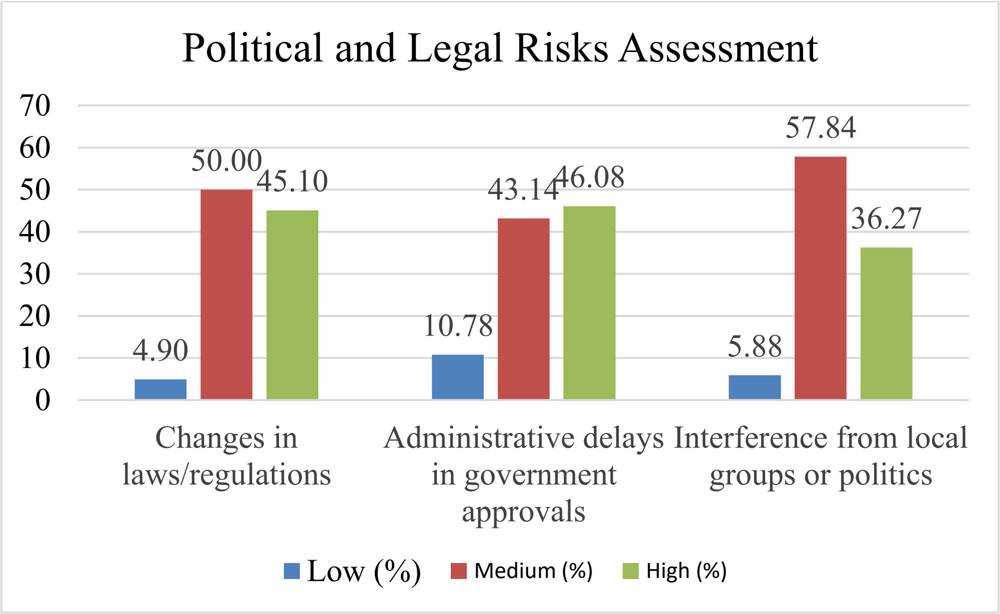
For the impact of foreign exchange fluctuations, 2.94% of respondents perceived it as low risk, 58.82% as medium risk, and 38.24% as high risk. This indicates a notable proportion recognizing currency volatility as a moderate economic risk in hydropower projects.

Similarly, regarding the effect of inflation on project budgeting, 4.90% rated it as low risk, 42.16% as medium risk, and 52.94% as high risk, showing that inflation is viewed as a major economic challenge affecting project cost control and overall budgeting reliability.

Overall, the findings indicate that while cost escalation due to imports and foreign exchange fluctuations are considered moderate economic risks, respondents expressed greater concern over inflation, which is seen as more significant factor that can substantially affect budgeting, cost control and the overall financial performance of hydropower projects.

F. Political and Legal Risks

Political and legal uncertainties emerged as another dominant risk category. Frequent policy changes, approval delays, and local political interference were reported as major impediments.



Calculated $\chi^2 = 5.91 < 9.49$, p-value > 0.05. So, not statistically significant.

Figure 4. 6 Political and Legal Risks Assessment

Figure 4.6 presents respondents' perceptions of the level of risk associated with political and legal factors in hydropower projects. The results show that 4.90% of respondents rated changes in laws and regulations as low risk, 50.00% as medium risk, and 45.10% as high risk, suggesting that while legal changes are acknowledged, they are generally perceived as moderate to high concern.

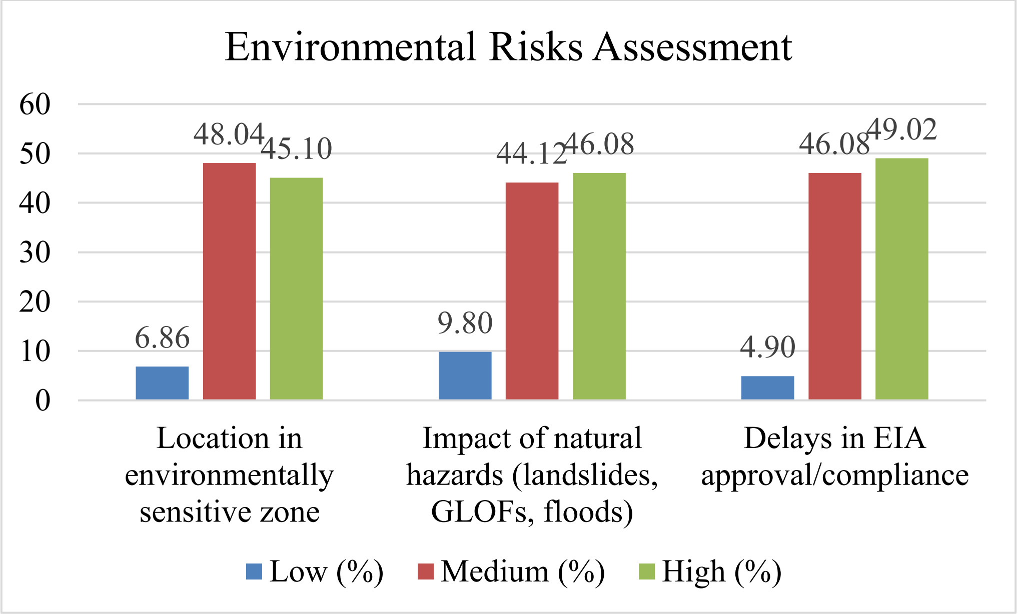
Regarding administrative delays in government approvals, 10.78% of respondents rated this factor as low risk, 43.14% as medium risk, and 46.08% as high risk. This indicates that delays in obtaining necessary permits and approvals are seen as a recurring issue that can moderately to significantly affect project timelines.

For interference from local groups or political influences, 5.88% rated it as low risk, 57.84% as medium risk, and 36.27% as high risk. This shows that social and political interference is viewed as a moderate concern that can disrupt project implementation and increase uncertainty.

Overall, the findings indicate that while changes in laws and regulations and political or social interferences are generally seen as moderate risks, administrative delays remain more prominent challenges in hydropower projects. Respondents highlighted that delays in government approvals can significantly affect project timelines, while local and political interference can create uncertainties in project execution, emphasizing the importance of proactive engagement with regulatory bodies and community stakeholders to mitigate potential disruptions.

G. Environmental Risks

Environmental risks were rated moderately high, particularly those linked to landslides, floods, and GLOFs. Delays in Environmental Impact Assessment (EIA) approval and compliance processes and projects located in environmentally sensitive zones were identified as facing severe operational risks during monsoon seasons.



Calculated $\chi^2 = 1.28 < 9.49$, p-value > 0.05. So, not statistically significant.

Figure 4. 7 Environmental Risks Assessment

Figure 4.7 presents the respondents' views on the degree of risk linked to environmental factors in hydropower projects. The results indicate that 6.86% of respondents rated the location in environmentally sensitive zones as having a low risk, 48.04% as medium risk, and 45.10% as high risk, suggesting moderate to high concern regarding the siting of projects in sensitive areas.

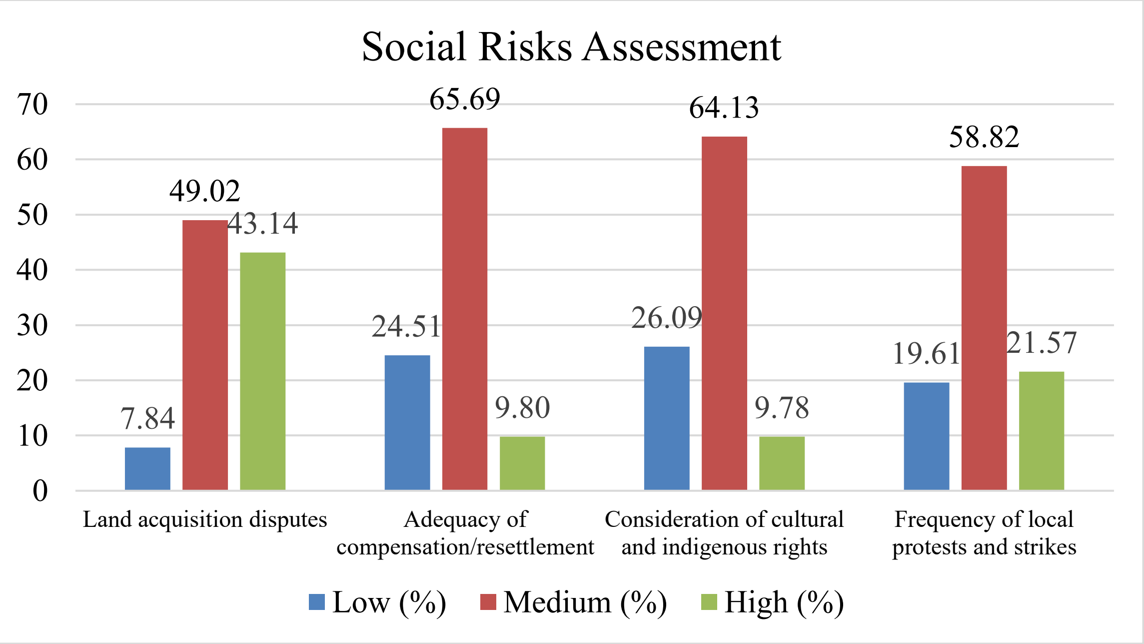
For the impact of natural hazards such as landslides, GLOFs, and floods, 9.80% of respondents rated it as low risk, 44.12% as medium risk, and 46.08% as high risk, reflecting moderate to high concern regarding the impact of potential hazard-related risks.

Regarding delays in Environmental Impact Assessment (EIA) approval and compliance, 4.90% of respondents considered it low risk, 46.08% medium risk, and 49.02% high risk, indicating that regulatory and procedural delays are perceived as medium to major risk factor in project planning and execution.

Overall, the findings suggest that while respondents see moderate risk associated with environmentally sensitive locations, they are more concerned about regulatory delays and natural hazard impacts that can critically affect project timelines and sustainability.

H. Social Risks

Social issues such as land acquisition disputes, inadequate compensation, and community protests were common. Respect for cultural and indigenous rights was also highlighted as an area requiring stronger attention.



Calculated $\chi^2 = 32.94 \gg 12.59$, p-value < 0.001.
So, statistically significant.

Figure 4. 8 Social Risks Assessment

Figure 4.8 illustrates the respondents' views on the degree of risk associated with land-related factors in hydropower projects. The results show that 7.84% of respondents rated the risk of land acquisition disputes as low, 49.02% as medium, and 43.14% as high, indicating moderate to major concern in this area.

Regarding the adequacy of compensation and resettlement measures, 24.51% of respondents considered the risk low, 65.69% medium, and 9.80% high, suggesting a moderate concern regarding adequacy of compensation and resettlement.

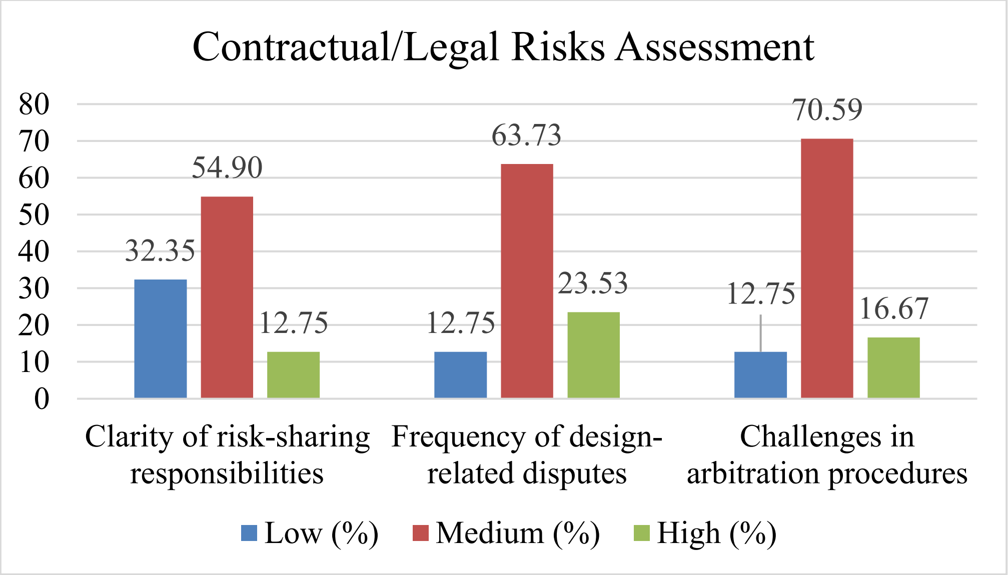
Similarly, for the consideration of cultural and indigenous rights, 26.09% rated it as low risk, 64.13% as medium, and 9.78% as high, highlighting that respondents perceive potential challenges in respecting local cultural and indigenous rights as a moderate source of risk.

In terms of the frequency of local protests and strikes, 19.61% of respondents rated the risk low, 58.82% medium, and 21.57% high, indicating that social unrest and community opposition are considered moderate risks in land-related aspects of hydropower projects.

Overall, the findings suggest that respondents see land acquisition disputes, compensation adequacy, cultural rights and community actions as moderately risky, which can substantially influence project progress and stakeholder acceptance.

I. Contractual and Legal Risks

Contractual disputes and unclear allocation of responsibilities were perceived as substantial threats. Poorly defined BOOT contracts and complex arbitration procedures also increased uncertainty.



Calculated $\chi^2 = 26.42 \gg 9.488$, p-value < 0.001.
So, statistically significant.

Figure 4. 9 Contractual/Legal Risks Assessment

Figure 4.9 presents respondents' perceptions of the level of risk associated with contractual and dispute-related factors in hydropower projects. The results show that, for the clarity of risk-sharing responsibilities, 32.35% of respondents rated it as low risk, 54.90% as medium risk, and 12.75% as high risk, indicating moderate concern about unclear allocation of responsibilities.

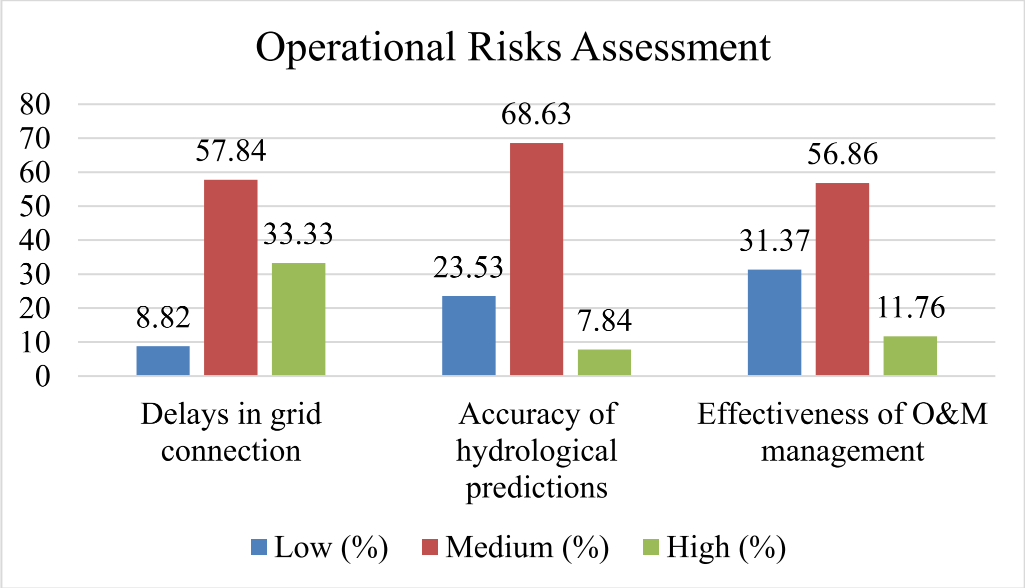
Regarding the frequency of design-related disputes, 12.75% of respondents rated it as low risk, 63.73% as medium risk, and 23.53% as high risk, suggesting that disputes are considered a moderate source of risk in project execution.

Similarly, for challenges in arbitration procedures, 12.75% of respondents considered it low risk, 70.59% medium, and 16.67% high risk, highlighting that difficulties in dispute resolution are perceived as a moderate risk factor.

Overall, the findings suggest that risk-sharing responsibilities, occurrence of disputes and effectiveness of arbitration procedures are moderately concerning, that can critically affect project management and contractual performance.

J. Operational Risks

Operational risks were associated mainly with grid connection delays, inaccurate hydrological predictions, and ineffective O&M management.



Calculated $\chi^2 = 35.79 \gg 9.488$, p-value < 0.001. So, statistically significant.

Figure 4. 10 Operational Risks Assessment

Figure 4.10 illustrates respondents' perceptions of the level of risk associated with operational and technical factors in hydropower projects. The results show that, regarding delays in grid connection, 8.82% of respondents rated it as low risk, 57.84% as medium risk, and 33.33% as high risk, indicating a moderate concern about potential connectivity issues.

For the accuracy of hydrological predictions, 23.53% of respondents considered the risk low, 68.63% medium, and 7.84% high, suggesting that uncertainties in hydrological forecasting are viewed as a moderate factor that could affect project planning and performance.

In terms of the effectiveness of operation and maintenance (O&M) management, 31.37% rated it as low risk, 56.86% as medium risk, and 11.76% as high risk, reflecting moderate concern about the capacity of O&M practices to sustain project performance over time.

Overall, these findings indicate that respondents are moderately concerned about delays in grid connection, hydrological uncertainties and O&M effectiveness as critical risk factors in hydropower project management.

4.2.2 Statistical Significance of Risk Categories

A Chi-square test was conducted to assess the statistical significance of the responses. The findings indicated that the majority of risk categories such as design, financial, resource, and operational risks were statistically significant ($p < 0.05$), thereby validating the reliability of the dataset for subsequent analysis.

Table 4. 5 Statistical Significance of Risk Categories

Risk Category	Chi-square Value	Critical Value	p-value	Significance
Design Risks	211.7	12.59	<0.001	Significant
Management & Coordination Risks	33.22	9.49	<0.001	Significant
Resource Risks	60.36	9.49	<0.001	Significant
Financial Risks	135.26	15.51	<0.001	Significant
Economic Risks	16.03	9.49	<0.01	Significant
Political & Legal Risks	5.91	9.49	>0.05	Not Significant
Environmental Risks	1.28	9.49	>0.05	Not Significant
Social Risks	32.94	12.59	<0.001	Significant
Contractual Risks	26.42	9.49	<0.001	Significant
Operational Risks	35.79	9.49	<0.001	Significant

4.2.3 Contribution of Risk Categories to Hydropower Project Impact

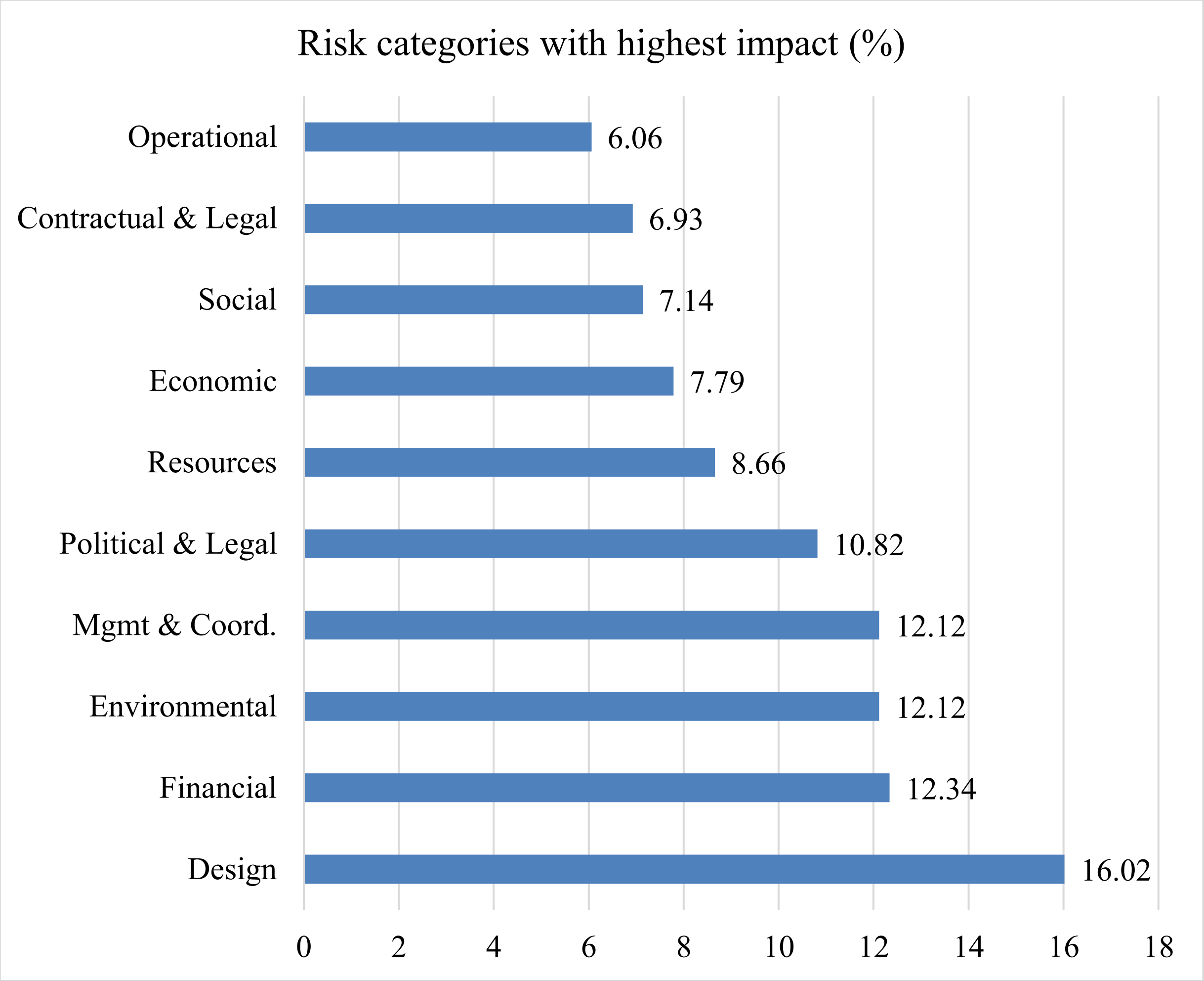


Figure 4. 11 Contribution of Risk Categories to Hydropower Project Impact

Figure 4.11 presents the risk categories that respondents identified as having the greatest percentage impact on hydropower projects. The results show that Design risks have the highest impact at 16.02%, followed by Financial risks at 12.34%, and both Environmental and Management & Coordination risks at 12.12%. Political and Legal risks account for 10.82%, Resources-related risks 8.66%, and Economic risks 7.79%. Social risks stand at 7.14%, Contractual & Legal risks at 6.93% and Operational risks at 6.06%.

Overall, the results indicate that design-related, financial, and environmental risks are considered to exert the greatest influence on hydropower projects. Conversely, operational, contractual, and social risks are considered to have comparatively lower influence. These results highlight the importance of prioritizing design quality, financial planning, and environmental management to enhance risk mitigation strategies in hydropower projects.

4.2.4 Comparative Analysis of Hydropower Project Risks in South Asian Countries

The following table compares the main risks and challenges faced by hydropower projects in Nepal, Bhutan, India, and Pakistan. These risks are categorized based on environmental, geological, financial and institutional factors encountered in each country. Understanding these key risks helps in evaluating the hurdles that influence hydropower development and their impact on project planning, financing and execution.

Table 4. 6 Comparison of top risks with other South Asian nations

Country	Top Risks	Source / Study Context	Reasons
Nepal	Design Risk; Financial Risk; Environmental Risk; Management & Coordination Risk	This Study	Complex Himalayan geology; delays in environmental approvals; financing and investment constraints; hydrological variability.
Bhutan	Topographic and geological conditions; costs associated with equipment and transmission; financing-related expenses; institutional expenditures; and social and environmental safeguard costs.	Ogino et al., 2019	Difficult Himalayan terrain; imported equipment and remote access increasing costs; reliance on external financing; administrative procedures; strict environmental protection policies.
India	Financial condition of project developer; Environmental impact; Rock weathering condition; Rainfall intensity and distribution; Public acceptance	Agarwal & Kansal, 2020	Financial constraints of developers; lengthy environmental clearance processes; weak/variable rock conditions in Himalayas; monsoon rainfall affecting construction; community and land acquisition concerns.
Pakistan	Project execution risks; Geological & hydrological risks; Planning risks; Contract risks; Procurement risks	Ayub et al., 2016	Weak project management and coordination; complex geology and river flow variability; inadequate feasibility and planning; contractual disputes; delays in procurement and equipment supply.

This table summarizes the key risks in hydropower development in these four countries, highlighting the unique and shared challenges faced in each context. Understanding these factors is essential for future planning and risk mitigation strategies in the hydropower sector.

4.2.5 Weight Assignment of Risk Categories

To reflect the relative importance of different risk categories, weights were assigned based on expert judgment and literature review. The weighting scheme ensures that critical risks have a greater influence on the final index.

Table 4. 7 Weight Distribution of Risk Categories

Category	% composition	Hydropower-Specific Risk Factors
A. Design Risks	20%	1. Incomplete geological & hydrological investigation
		2. Poor dam design or tunnel alignment
		3. Difficult topography & terrain
		4. Lack of adaptability to remote site conditions
B. Management and Coordination Risks	10%	1. Poor coordination between contractors, consultants & local authorities
		2. Inexperience in managing hydropower complexity
		3. Ineffective stakeholder communication
C. Resource Risks	10%	1. Remote access leads to supply delays
		2. Skilled hydropower workforce shortages
		3. Equipment inaccessibility or unsuitability for terrain
D. Financial Risks	15%	1. Reliability and Creditworthiness of the Offtaker (Buyer)
		2. Grid Availability and Dispatch Risk
		3. Delay in financial closure
		4. Difficulty in securing private sector investment
		5. Underestimation of tunnel or powerhouse costs
E. Economic Risks	5%	1. Cost escalation due to imported machinery
		2. Foreign exchange risks for loan repayments
		3. Inflation during long project durations
F. Political and Legal Risks	10%	1. Unstable regulatory framework
		2.Bureaucratic delays in permits
		3. Local-level opposition or interference
G. Environmental Risks	10%	1. High environmental sensitivity of project area (protected zones, rivers)
		2. Landslides, glacial lake outburst floods (GLOFs), monsoon floods
		3. Delays due to EIAs and compliance
H. Social Risks	5%	1. Land acquisition disputes
		2. Inadequate compensation or resettlement
		3. Cultural/indigenous rights violations
		4. Protest and local strikes
I. Contractual/ Legal Risks	5%	1. Ambiguous risk-sharing clauses in BOOT contracts
		2. Claims and disputes over design responsibility
		3. International arbitration complexities
		1. Delays in grid connection

J. Operational Risks	10%	2. Generation below expected capacity due to poor hydrological prediction
		3. O&M challenges post-construction

4.2.6 Normalization of Risk Factors

To ensure comparability and proportional contribution of each risk factor, the mean value of each factor was multiplied by its corresponding assigned weight to obtain a weighted score. However, since these weighted scores vary in magnitude, a normalization process was carried out to standardize their relative influence within the overall index. The normalized weight of each risk factor was calculated using Equation 4.1.

$$W_i' = \frac{w_i \cdot x_i}{\sum(w_i \cdot x_i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Equation 4.1}$$

where:

w_i= assigned weight of the risk factor

x_i= mean score of the risk factor

Table 4.8 presents the calculated mean scores along with the respective normalized weights for each of the identified risk factors.

Table 4. 8 Average Rating and Normalized Weight

S. No.	**Risk Factors**	**Avg. rating (W_i)**	**Normalized weight (Wi’)**
1	Incomplete geological & hydrological investigation	8.88	0.0436
2	Poor dam design or tunnel alignment	6	0.0294
3	Difficult topography & terrain	17.36	0.0851
4	Lack of adaptability to remote site conditions	8.33	0.0409
5	Poor coordination between contractors, consultants & local authorities	6.207	0.0304
6	Inexperience in managing hydropower complexity	4.08	0.0200
7	Ineffective stakeholder communication	4.9	0.0240
8	Remote access leads to supply delays	8.276	0.0406
9	Skilled hydropower workforce shortages	3.99	0.0196
10	Equipment inaccessibility or unsuitability for terrain	4.38	0.0215
11	Reliability and Creditworthiness of the Offtaker (Buyer)	5.775	0.0283
12	Grid Availability and Dispatch Risk	9.6	0.0471
13	Delay in financial closure	11.46	0.0562

14	Difficulty in securing private sector investment	4.605	0.0226
15	Underestimation of tunnel or powerhouse costs	10.62	0.0521
16	Cost escalation due to imported machinery	3.72	0.0182
17	Foreign exchange risks for loan repayments	3.45	0.0169
18	Inflation during long project durations	3.775	0.0185
19	Unstable regulatory framework	7.15	0.0351
20	Bureaucratic delays in permits	7.56	0.0371
21	Local-level opposition or interference	7.851	0.0385
22	High environmental sensitivity of project area (protected zones, rivers)	7.54	0.0370
23	Landslides, glacial lake outburst floods (GLOFs), monsoon floods	7.05	0.0346
24	Delays due to EIAs and compliance	7.45	0.0365
25	Land acquisition disputes	3.53	0.0173
26	Inadequate compensation or resettlement	2.175	0.0107
27	Cultural/indigenous rights violations	1.925	0.0094
28	Protest and local strikes	2.5	0.0123
29	Ambiguous risk-sharing clauses in BOOT contracts	2.66	0.0130
30	Claims and disputes over design responsibility	2.89	0.0142
31	International arbitration complexities	2.845	0.0140
32	Delays in grid connection	6.44	0.0316
33	Generation below expected capacity due to poor hydrological prediction	3.6	0.0177
34	O&M challenges post-construction	5.32	0.0261

4.2.7 Calculation of Hydropower Risk Index (HRI)

The Hydropower Risk Index (HRI) was derived by aggregating the weighted contributions of normalized risk factors, where each factor's influence is scaled by its proportional composition. The base HRI is obtained by summing the products of average risk ratings and their respective weights, while the maximum HRI is computed using the maximum possible risk ratings under the same weighting scheme. This comparative framework enables standardized evaluation of overall hydropower risk intensity by contrasting observed risk conditions against theoretical upper-bound risk exposure.

Table 4. 9 Hydropower Risk Index (HRI) Calculation Using Weighted Risk Factors

Avg. rating of risk factors (X_i)	**% composition of risks**	**Weightage of risk factors = X_i*% composition**	**Base HRI score**	**Max. rating of risk factors (X_i)**	**% composition of risks**	**Max. weightage of risk factors = X_i*% composition**	**Max. value of HRI score**
44.4	0.2	8.88	0.3867	102	0.2	20.4	1.1493
30	0.2	6	0.1766	102	0.2	20.4	1.1493

86.8	0.2	17.36	1.4781	102	0.2	20.4	1.1493
41.65	0.2	8.33	0.3403	102	0.2	20.4	1.1493
62.07	0.1	6.207	0.1890	102	0.1	10.2	0.2873
40.8	0.1	4.08	0.0816	102	0.1	10.2	0.2873
49	0.1	4.9	0.1178	102	0.1	10.2	0.2873
82.76	0.1	8.276	0.3359	102	0.1	10.2	0.2873
39.9	0.1	3.99	0.0781	102	0.1	10.2	0.2873
43.8	0.1	4.38	0.0941	102	0.1	10.2	0.2873
38.5	0.15	5.775	0.1636	102	0.15	15.3	0.6465
64	0.15	9.6	0.4520	102	0.15	15.3	0.6465
76.4	0.15	11.46	0.6441	102	0.15	15.3	0.6465
30.7	0.15	4.605	0.1040	102	0.15	15.3	0.6465
70.8	0.15	10.62	0.5532	102	0.15	15.3	0.6465
74.4	0.05	3.72	0.0679	102	0.05	5.1	0.0718
69	0.05	3.45	0.0584	102	0.05	5.1	0.0718
75.5	0.05	3.775	0.0699	102	0.05	5.1	0.0718
71.5	0.1	7.15	0.2507	102	0.1	10.2	0.2873
75.6	0.1	7.56	0.2803	102	0.1	10.2	0.2873
78.51	0.1	7.851	0.3023	102	0.1	10.2	0.2873
75.4	0.1	7.54	0.2788	102	0.1	10.2	0.2873
70.5	0.1	7.05	0.2438	102	0.1	10.2	0.2873
74.5	0.1	7.45	0.2722	102	0.1	10.2	0.2873
70.6	0.05	3.53	0.0611	102	0.05	5.1	0.0718
43.5	0.05	2.175	0.0232	102	0.05	5.1	0.0718
38.5	0.05	1.925	0.0182	102	0.05	5.1	0.0718
50	0.05	2.5	0.0307	102	0.05	5.1	0.0718
53.2	0.05	2.66	0.0347	102	0.05	5.1	0.0718
57.8	0.05	2.89	0.0410	102	0.05	5.1	0.0718
56.9	0.05	2.845	0.0397	102	0.05	5.1	0.0718
64.4	0.1	6.44	0.2034	102	0.1	10.2	0.2873
36	0.1	3.6	0.0636	102	0.1	10.2	0.2873
53.2	0.1	5.32	0.1388	102	0.1	10.2	0.2873
Total	**3.55**	**203.894**	**7.6736**	**Total**	**3.55**	**362.1**	**12.8577**

4.2.8 Relative HRI Calculation

The Relative Hydropower Risk Index (HRI) is computed to standardize the aggregated risk score against its theoretical maximum value, enabling comparative interpretation across projects or scenarios.

$$\text{Relative HRI} = \frac{\text{Computed HRI}}{\text{Max. value of HRI}} * 100\%$$

$$= \frac{7.673559673}{12.85774648} * 100\%$$

$$= 59.68\%$$

The resulting Hydropower Risk Index (HRI) of 59.68% is a weighted composite score, representing the cumulative risk potential derived from the combined influence of all identified risk factors. A medium HRI (41-60) indicates a moderate overall exposure to critical risks, reflecting a balanced sensitivity of project cost, schedule, quality and operational performance to these factors within the hydropower project environment. The HRI serves as a practical decision-making tool for stakeholders and forms the foundation for developing risk mitigation strategies in the next objective.

Although the calculated HRI yields an absolute value, it is not directly comparable across different studies, project contexts, or scales, as it depends on the number of considered factors, their assigned weights, and the rating scale applied. Therefore, a Relative HRI is used for meaningful comparison. Ultimately, the results were interpreted using a five-level rating system, as presented in Table 4.10.

Table 4. 10 Five-Level Rating System

HRI Range	**Performance Label**	**Visual Star Rating**	**Interpretation**
0 – 20	Very Low Risk	★	Indicates excellent risk management; project is highly secure against delays, cost overruns, and safety issues.
21 – 40	Low Risk	★★	Suggests good risk control; minor issues may arise but are unlikely to affect overall project performance.
41 – 60	Moderate Risk	★★★	Represents moderate exposure; project requires careful monitoring and proactive mitigation of potential risks.
61 – 80	High Risk	★★★★	Indicates significant risk; delays, cost escalation, or operational challenges are likely without mitigation.
81 – 100	Very High Risk	★★★★★	Denotes critical risk; urgent and comprehensive risk management strategies are necessary to safeguard project success.

Furthermore, sensitivity analysis was carried out, where top 2 most sensitive risk factors (x_1, x_2) were varied within a plausible range by ±5%, ±10%, ±15%, ±20% and how overall HRI index changes were observed, which is given in detail in APPENDIX 4.

Table 4. 11 Sensitivity Analysis of Top 2 Risk Factors on Hydropower Risk Index (HRI)

Variation in Weights (x1, x2)	HRI Score (0–100)	Absolute Change	% Change from Baseline
For x1			
Baseline (0%)	59.68%	–	–
5%	60.74%	1.06%	1.78%
10%	61.71%	2.03%	3.40%
15%	62.73%	3.05%	5.11%
20%	63.79%	4.11%	6.89%
−5%	58.96%	-0.72%	-1.21%
−10%	58.14%	-1.54%	-2.58%
−15%	57.37%	-2.31%	-3.86%
−20%	56.66%	-3.02%	-5.06%
For x2			
Baseline (0%)	59.68%	–	–
5%	59.83%	0.15%	0.25%
10%	59.99%	0.31%	0.51%
15%	60.16%	0.48%	0.80%
20%	60.34%	0.66%	1.11%
−5%	59.55%	-0.13%	-0.22%
−10%	59.43%	-0.26%	-0.43%
−15%	59.32%	-0.36%	-0.61%
−20%	59.22%	-0.46%	-0.77%

Table 4.11 presents a summary of the sensitivity analysis results. The initial baseline value of the Hydropower Risk Index (HRI) was determined to be 59.68. Increasing the weight of the first risk factor (x_1) by 5–20% raised the HRI slightly to 60.74–63.79 (+1.06 to +4.11 points, or +1.78% to +6.89%), while reducing x_1 by the same amounts lowered the HRI to 58.96–56.66 (-0.72 to -3.02 points, or -1.21% to -5.06%). Variations in the second risk factor (x_2) had minimal effect: increasing x_2 by 5–20% changed the HRI to 59.83–60.34 (+0.15 to +0.66 points, +0.25% to +1.11%), and decreasing it led to 59.55–59.22 (-0.13 to -0.46 points, -0.22% to -0.77%). Overall, even with ±20% weight adjustments, HRI shifts remain small, demonstrating the index's stability and robustness and indicating that minor differences in expert judgment or weighting have little impact on hydropower risk assessment.

Likewise, a correlation analysis was conducted to assess the consistency between the assigned risk factor weights and the computed HRI scores using Pearson's correlation coefficient (r). This coefficient quantifies both the magnitude and direction of the linear relationship between the two variables. The formula is given as follows:

$$r = \frac{\Sigma[(X - \bar{X})(Y - \bar{Y})]}{\sqrt{\Sigma(X - \bar{X})^2 \times \Sigma(Y - \bar{Y})^2}} \text{ .... Equation 4.2}$$

where X represents weights, Y represents HRI scores, and $\bar{X}, \bar{Y}$ are the means of X and Y.

Mean values were determined as $\bar{X} = 5.9969$ and $\bar{Y} = 182.6637$. Deviations from the mean, cross-products, and squares were computed for all 34 data points. Summations yielded $\Sigma(X - \bar{X})^2 = 341.8644$, $\Sigma(Y - \bar{Y})^2 = 590077.4$, and $\Sigma[(X - \bar{X})(Y - \bar{Y})] = 12640.19$.

Substituting these values, the correlation coefficient was calculated as:

$$r = \frac{12640.19}{\sqrt{341.8644 \times 590077.4}} = 0.889963$$

Since the correlation coefficient is greater than 0.80 (r > 0.80), it reflects a strong positive relationship between the assigned weights and the HRI scores.

The scatter plot presented in Figure 4.12 demonstrates a clear positive linear association between risk factor weightage and the HRI score. The regression equation, $y = 0.3697x - 0.3907$, indicates that for every one-unit increase in weightage, the HRI score increases by approximately 0.3697 units. Furthermore, the coefficient of determination ($R^2 = 0.7920$) suggests that about 79.20% of the variation in HRI scores is explained by this model, confirming a strong linear relationship between the variables. While most data points align with the trendline, some variability remains, particularly at higher weightages, implying that other factors also influence the HRI score. Overall, Risk Factor Weightage is a significant predictor of HRI, providing a reliable basis for risk assessment in hydropower projects.

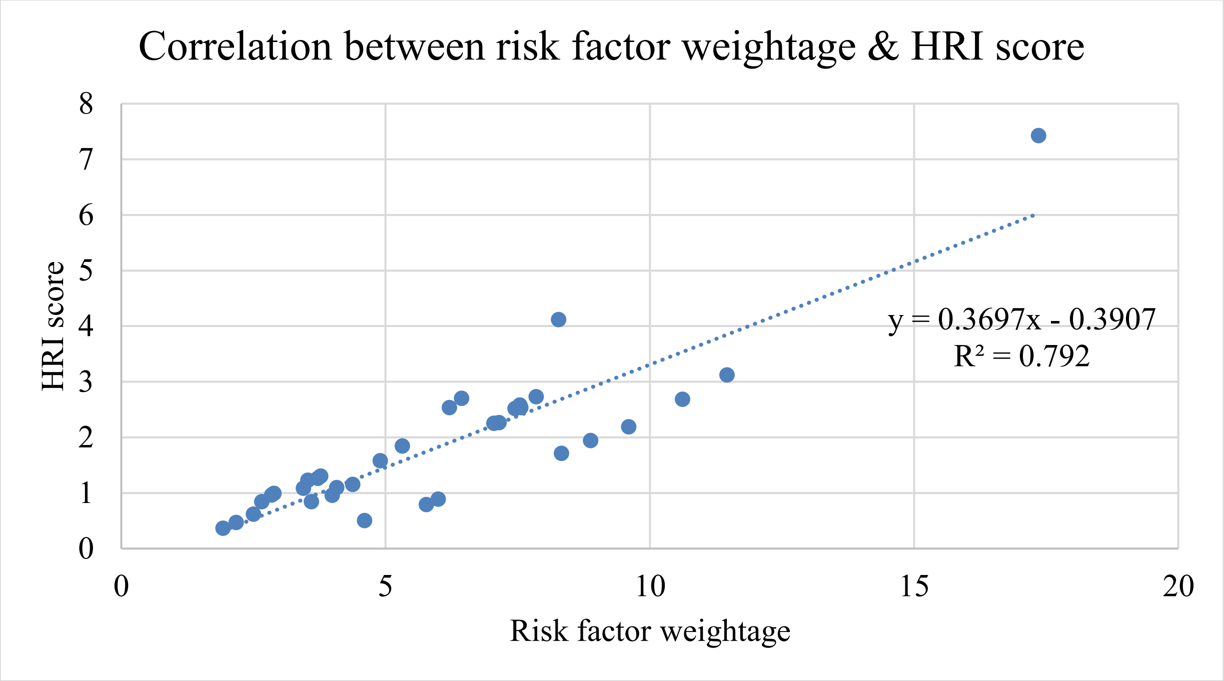


Figure 4. 12 Correlation between risk factor weightage & HRI score

4.2.9 Validation Based on Real Hydropower Projects

To validate the developed Hydropower Risk Index (HRI) model against real hydropower project conditions, expert validation was obtained from two practicing hydropower professionals at the Ministry of Energy, Water Resources and Irrigation (MoEWRI), as presented in APPENDIX 5. The first validation was provided by Senior Divisional Engineer (Hydropower) at MoEWRI, with approximately 23 years of professional experience, who assessed the model's approximate level of validity and accuracy at 95%, confirming that the model demonstrates a sound theoretical foundation and logical consistency, and that its outcomes are reasonably aligned with actual hydropower project conditions. The second validation was provided by Engineer (Hydropower) at MoEWRI, with 11 years of professional experience, who similarly examined the model with respect to its practical applicability, methodological soundness and consistency with real-world scenarios, and assessed its approximate level of validity and accuracy at 80%. Both validators independently concluded that the model is adequately reliable and acceptable for academic purposes, with its level of agreement exceeding the 70% threshold satisfactory for a Master's level research study, and further recognized its potential for practical implementation subject to context-specific considerations.

4.3 Recommendation of appropriate risk mitigation measures grounded in the analysis of the developed risk index.

The third objective of this study was to recommend appropriate risk mitigation measures for hydropower projects based on the findings of the Hydropower Risk Index (HRI) and stakeholder inputs. This objective was achieved by integrating questionnaire survey responses, Key Informant Interviews (KII) with hydropower experts and identification of high-impact risk categories. This section presents stakeholder perceptions on mitigation practices, evaluates the effectiveness of existing measures, and proposes structured mitigation strategies aligned with priority risk areas.

4.3.1 Stakeholder and Expert Perspectives on Risk Mitigation and HRI

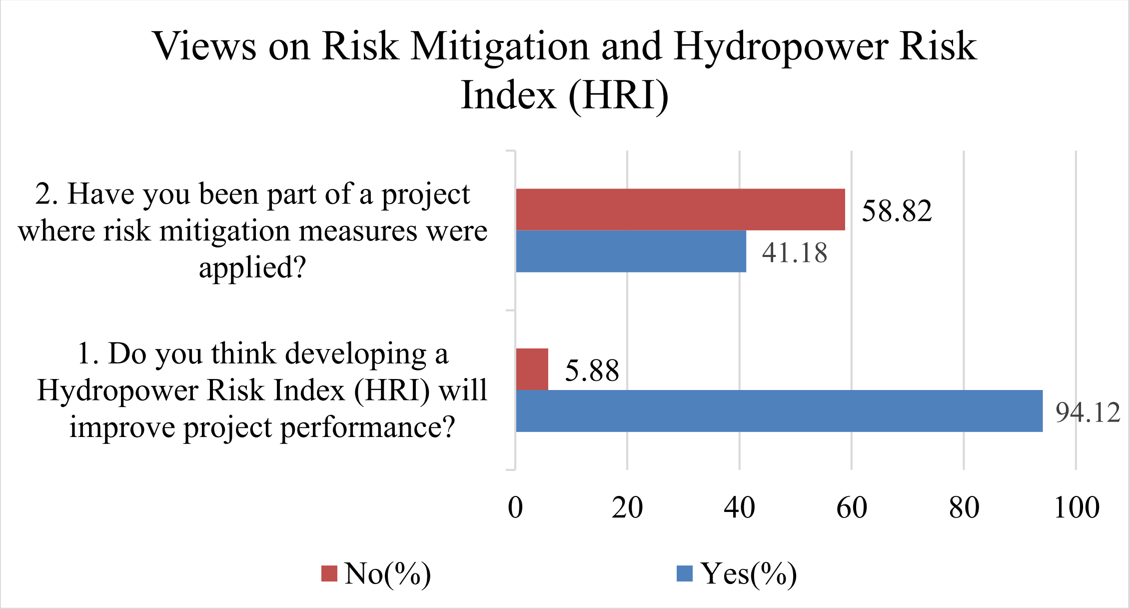


Figure 4. 13 Views on Risk Mitigation and Hydropower Risk Index (HRI)

The findings presented in Figure 4.13 indicate that while only 41.18% of respondents had prior experience with projects implementing risk mitigation measures, a significant majority (94.12%) agreed that developing a Hydropower Risk Index (HRI) would improve project performance, highlighting strong professional support for structured risk management tools. This gap between awareness and practical application suggests limited institutionalization of risk mitigation practices. Insights from KII further reveal that risk management in Nepal's hydropower sector is largely reactive and lacks standardized frameworks, with experts emphasizing the need for systematic tools like HRI to enhance early-stage planning, monitoring and informed decision-making.

4.3.2 Effectiveness of Existing Risk Mitigation Measures

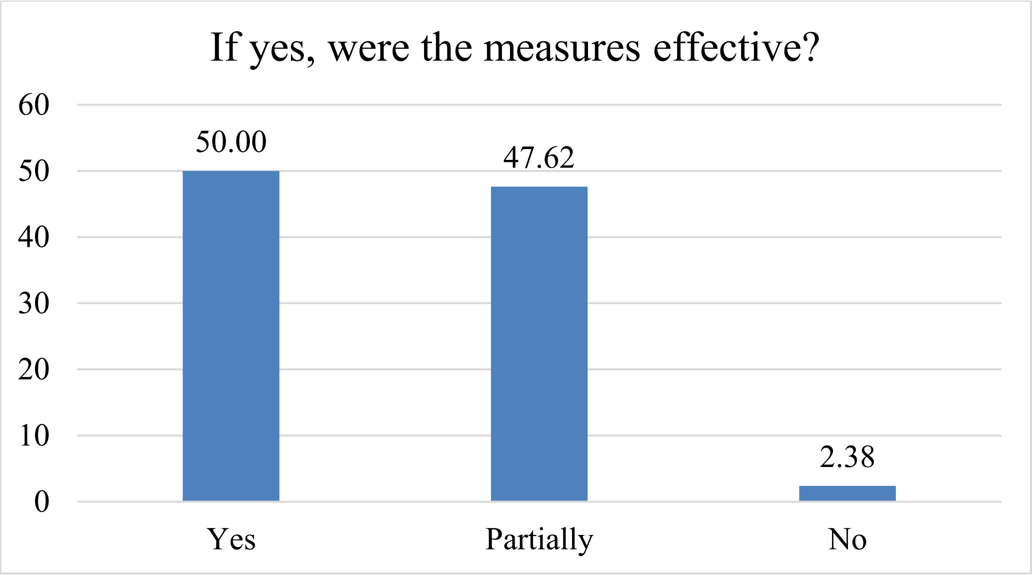


Figure 4. 14 Effectiveness of Applied Risk Mitigation Measures

As illustrated in Figure 4.14, the effectiveness of existing risk mitigation measures shows a mixed pattern, with 50% of respondents considering them fully effective, 47.62% partially effective, and 2.38% ineffective. This distribution indicates that although mitigation strategies are being implemented, they are not consistently achieving their intended outcomes. KII experts attributed this variability to shortcomings such as inadequate feasibility studies, weak coordination among project stakeholders, and insufficient monitoring and follow-up mechanisms. These findings highlight the need to strengthen both the design and execution of mitigation measures to ensure more reliable and comprehensive risk management in hydropower projects.

4.3.3 Identification of Priority Risk Areas for Mitigation

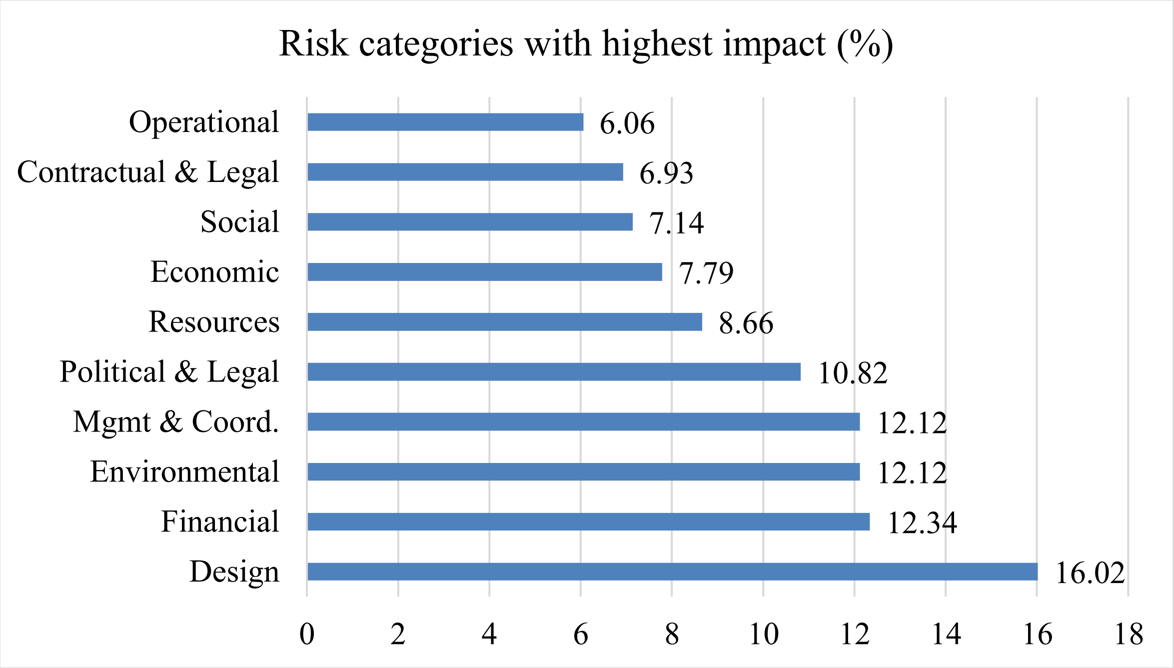


Figure 4. 15 Risk Categories with Highest Impact on Hydropower Projects

The identification of priority risk areas is based on the analysis of high-impact categories presented in Figure 4.15, where design, financial, environmental, and management & coordination risks were identified as the most critical contributors to project risk. These findings are supported by KII insights, which emphasize that complex geological conditions, financial uncertainties, environmental challenges, and institutional coordination gaps significantly influence project performance. This prioritization provides a focused basis for developing targeted mitigation strategies, ensuring that resources and management efforts are directed toward the most influential risk areas.

4.3.4 Recommended Risk Mitigation Strategies

Based on survey findings and expert inputs, a range of mitigation strategies is recommended across key domains, including technical, financial, managerial, environmental and institutional aspects. These include conducting detailed feasibility studies and site investigations to reduce design uncertainties, improving financial planning and contingency management, strengthening stakeholder coordination and communication mechanisms, enhancing environmental and social management practices, and reinforcing regulatory and institutional frameworks. KII experts particularly emphasized the importance of proactive risk identification and early-stage planning, noting that many project challenges originate from insufficient preparation rather than execution failures.

4.3.5 Integrated Framework for Risk Mitigation using HRI

The results suggest that effective risk mitigation requires an integrated and systematic framework that combines multiple dimensions of project management. The Hydropower Risk Index (HRI) serves as a structured tool for identifying, quantifying, and prioritizing risks, enabling continuous monitoring throughout the project lifecycle. KII experts highlighted that integrating HRI with modern tools such as BIM and digital monitoring systems can significantly improve real-time decision-making and risk control. This integrated approach facilitates a transition from reactive to proactive risk management practices.

4.3.6 Implications for Hydropower Project Management

The recommended mitigation measures provide practical guidance for improving hydropower project performance in Nepal by addressing key risk areas identified through both quantitative and qualitative analysis. The integration of survey findings and expert insights indicates that adopting structured risk management frameworks, supported by tools like HRI, can help reduce delays, control costs, and improve coordination among stakeholders. Overall, these measures contribute to more resilient, efficient, and sustainable hydropower project development.

4.4 Discussion

The analysis identified that design, financial, environmental, and management & coordination risks are the most critical factors influencing hydropower project performance, as presented in the HRI results. Among these, design risks showed the highest impact, primarily due to complex geological and topographical conditions, while financial risks were significant because of delays in financial closure and funding uncertainties. Environmental risks, including floods, landslides, and regulatory challenges, also contributed substantially, whereas management and coordination risks affected project efficiency through institutional and communication gaps.

The findings obtained through quantitative analysis were further supported and refined by qualitative insights from the Key Informant Interviews (KII). While the HRI provided a structured and numerical prioritization of risks, the experts emphasized practical challenges such as inadequate feasibility studies, weak stakeholder coordination, and limitations in implementation practices. Given that KII incorporates real-world experience and contextual understanding, these insights provide stronger validation and practical relevance to the analytical results.

Furthermore, the analysis indicates that technical and financial aspects carry greater importance compared to other risk categories, highlighting the need for improved design practices and financial planning in hydropower projects. In the context of Nepal, where complex terrain, environmental sensitivity, and institutional challenges prevail, effective risk management depends on integrating both quantitative tools like HRI and expert-driven decision-making to ensure sustainable and efficient project development.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Objective 1: To identify and evaluate critical risk factors influencing the performance of hydropower projects

Through an extensive review of relevant literature and a systematic validation process conducted by experts involving six senior hydropower professionals, a preliminary list of 41 risk factors was identified and subsequently refined to 34 validated factors, organized across ten major risk categories encompassing design, management and coordination, resource, financial, economic, political, environmental, social, contractual and operational risks. Factors receiving approval from at least four out of six experts were retained, ensuring contextual relevance and practical grounding. A structured questionnaire survey was conducted among 102 hydropower professionals, and descriptive statistical techniques were used to evaluate the perceived frequency and impact of each factor. The results indicated that design uncertainties, financial constraints, environmental concerns, and management-related issues are the most significant risk categories, whereas political, resource-related, social, and operational risks were found to have a moderate effect on overall project performance. This structured identification and categorization of risk factors provides a foundational evidence base for systematic risk assessment tailored to the unique geological, institutional, and socio-environmental conditions of Nepal's hydropower sector.

Objective 2: To develop a structured and context-specific Hydropower Risk Index (HRI) that quantifies the relative impact of identified risk factors

Building on the confirmed risk factors, a Hydropower Risk Index (HRI) was formulated as a composite quantitative framework to evaluate and prioritize risks based on their probability of occurrence and severity. Expert judgment was used to assign weights to each of the ten risk categories in order to reflect their relative importance. To maintain consistency across categories, all values were standardized to a common 0–100 scale. The final HRI score was obtained by aggregating these weighted and normalized results. The instrument's reliability and internal consistency were verified using Cronbach's Alpha, while a Chi-Square test was applied to assess whether significant differences existed in stakeholders' perceptions of risk levels. The robustness and validity of the developed index were further verified through sensitivity analysis and Pearson correlation testing, demonstrating that the HRI accurately and consistently captures the relative impact of identified risk factors. The index was additionally validated against real hydropower project conditions by two practicing engineers from the Ministry of Energy, Water Resources and Irrigation (MoEWRI), who assessed its validity and accuracy at 95% and 80% respectively, both confirming that the model's level of agreement exceeds the 70% threshold satisfactory for a Master's level research study. The resulting HRI provides a practical, replicable, and context-sensitive framework for risk prioritization in Nepal's hydropower sector.

Objective 3: To recommend appropriate risk mitigation measures grounded in the analysis of the developed risk index

Informed by the HRI analysis, qualitative feedback from survey respondents, Key Informant Interview (KII) findings from domain experts and supporting evidence from the literature, targeted and evidence-based risk mitigation measures were recommended for each identified risk category. These recommendations focus on strengthening design practices through thorough geological and hydrological investigations, improving financial planning and securing timely financial closure, enhancing coordination among contractors, consultants and local authorities, ensuring rigorous environmental compliance and effectively managing political, social and operational challenges throughout the project lifecycle. By directly linking mitigation strategies with the risk priorities established by the HRI, the recommendations support efficient resource allocation, informed decision-making and improved project performance. Overall, the study concludes that the HRI offers a structured, quantitative and practically validated approach to risk management, contributing to more efficient, resilient and sustainable hydropower development in Nepal.

5.2 Recommendations from the Study

Based on the results of this study, the following recommendations are put forward to improve risk management practices in hydropower projects:

1. Stakeholders, including clients, contractors, consultants, and policymakers, should be made aware of the importance of structured risk management through targeted awareness programs, emphasizing the role of the Hydropower Risk Index (HRI) in improving overall project performance.
2. The Hydropower Risk Index (HRI) developed in this study is recommended to be adopted as a decision-support tool during project planning, feasibility analysis, and risk prioritization to facilitate informed and evidence-based decision-making.
3. Structured training and capacity-building programs should be developed and

implemented for project managers, engineers, and relevant government officials to enhance their skills in risk identification, assessment techniques, and the practical application of HRI in project monitoring.

4. Project resources such as time, budget, and human capital should be allocated in a strategic manner, focusing on the most significant risk factors identified in this study, especially those that have a major influence on project cost, schedule, and overall performance.
5. Risk management practices should be institutionalized by integrating standardized risk assessment frameworks, including the HRI, into national guidelines and policies governing hydropower project development in Nepal to ensure consistency, accountability, and improved project outcomes.

5.3 Recommendations for Further Study

Considering the scope and constraints of this study, the following suggestions are put forward for future research:

1. Future HRI applications could be integrated with KPI frameworks to link risk exposure to project performance metrics, as suggested by (Bhattarai et al., 2024).
2. The application of the Hydropower Risk Index (HRI) should be extended acrosss diverse geographical regions and varying project scales to enhance its external validity and generalizability.
3. Future studies should prioritize creating a dynamic, lifecycle-oriented HRI model that reflects changes in risk levels throughout different stages of a project, such as planning, construction, and operation.
4. It is also recommended to incorporate advanced analytical techniques and digital technologies, including Building Information Modeling (BIM), Artificial Intelligence, and Machine Learning, to support predictive and real-time risk evaluation.
5. Empirical validation of the HRI model through its application in real-world hydropower projects, supported by longitudinal case studies, is necessary to improve its reliability and practical applicability.

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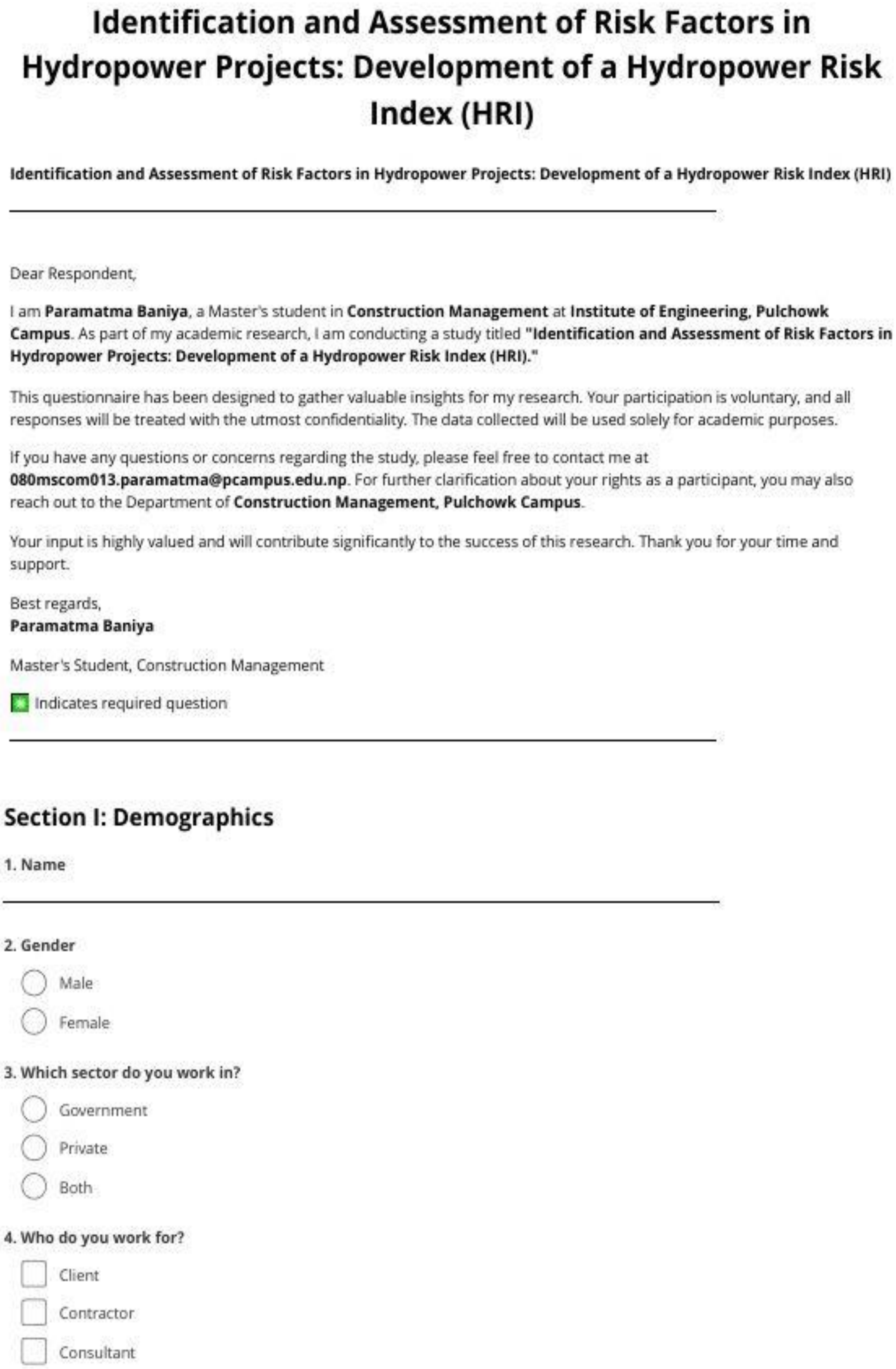
APPENDIX 1: Questionnaire



Identification and Assessment of Risk Factors in Hydropower Projects: Development of a Hydropower Risk Index (HRI)

Identification and Assessment of Risk Factors in Hydropower Projects: Development of a Hydropower Risk Index (HRI)

Dear Respondent,

I am **Paramatma Baniya**, a Master's student in **Construction Management** at **Institute of Engineering, Pulchowk Campus**. As part of my academic research, I am conducting a study titled **"Identification and Assessment of Risk Factors in Hydropower Projects: Development of a Hydropower Risk Index (HRI)."**

This questionnaire has been designed to gather valuable insights for my research. Your participation is voluntary, and all responses will be treated with the utmost confidentiality. The data collected will be used solely for academic purposes.

If you have any questions or concerns regarding the study, please feel free to contact me at **080mscom013.paramatma@pcampus.edu.np**. For further clarification about your rights as a participant, you may also reach out to the Department of **Construction Management, Pulchowk Campus**.

Your input is highly valued and will contribute significantly to the success of this research. Thank you for your time and support.

Best regards,
Paramatma Baniya

Master's Student, Construction Management

* Indicates required question

Section I: Demographics

1. Name

2. Gender

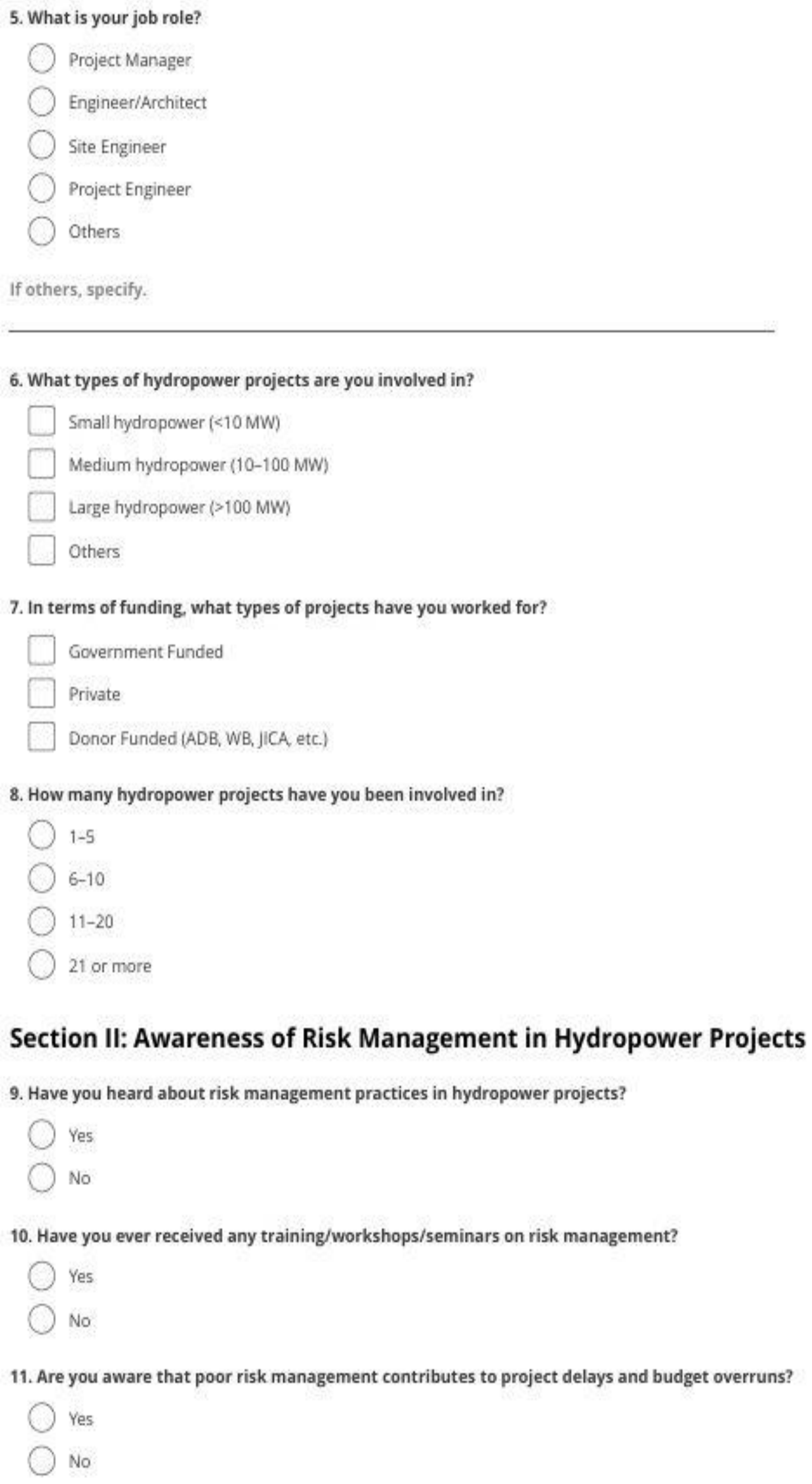
○ Male
○ Female

3. Which sector do you work in?

○ Government
○ Private
○ Both

4. Who do you work for?

☐ Client
☐ Contractor
☐ Consultant



5. What is your job role?

○ Project Manager
○ Engineer/Architect
○ Site Engineer
○ Project Engineer
○ Others

If others, specify.

____

6. What types of hydropower projects are you involved in?

☐ Small hydropower (<10 MW)
☐ Medium hydropower (10–100 MW)
☐ Large hydropower (>100 MW)
☐ Others

7. In terms of funding, what types of projects have you worked for?

☐ Government Funded
☐ Private
☐ Donor Funded (ADB, WB, JICA, etc.)

8. How many hydropower projects have you been involved in?

○ 1–5
○ 6–10
○ 11–20
○ 21 or more

Section II: Awareness of Risk Management in Hydropower Projects

9. Have you heard about risk management practices in hydropower projects?

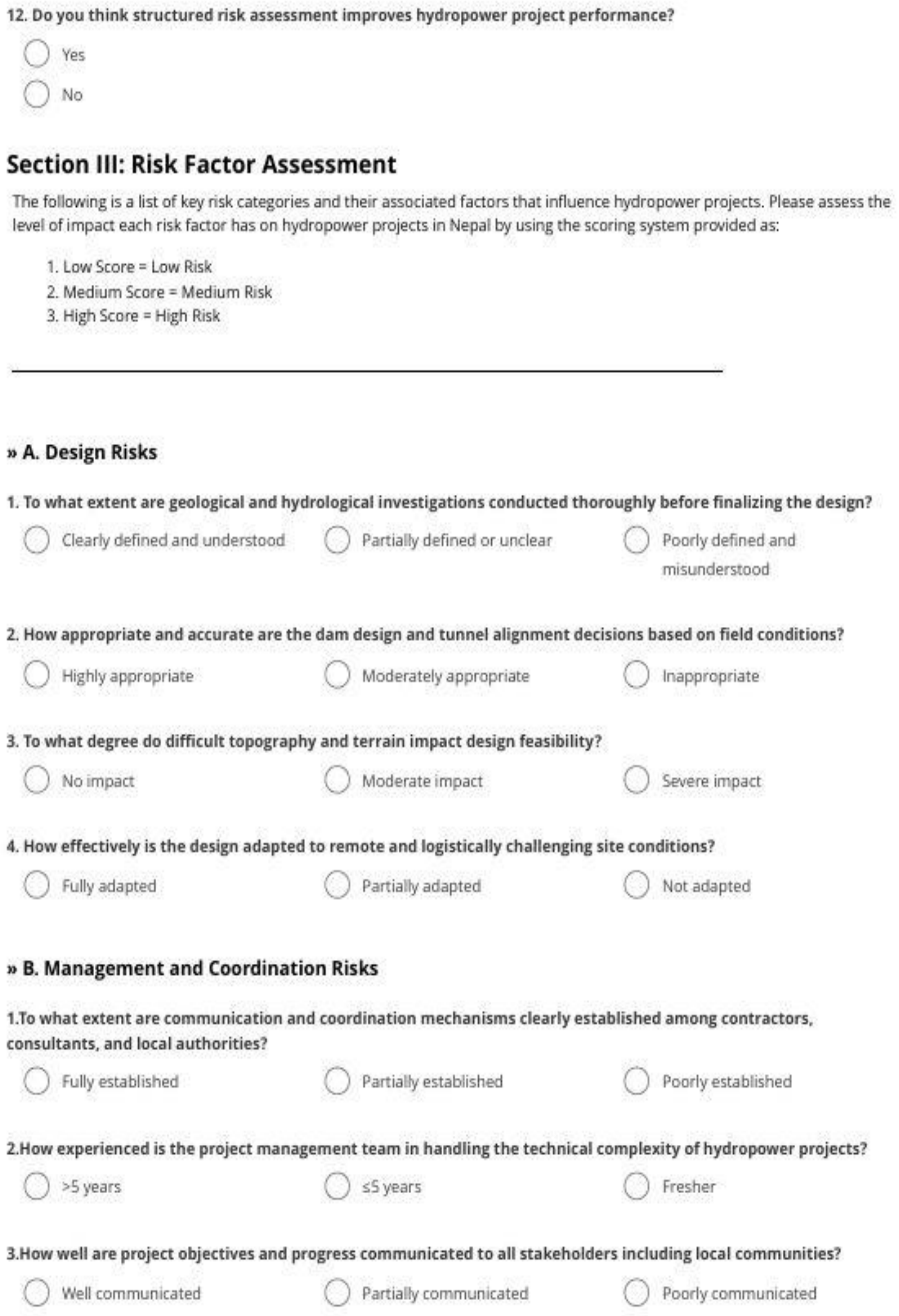
○ Yes
○ No

10. Have you ever received any training/workshops/seminars on risk management?

○ Yes
○ No

11. Are you aware that poor risk management contributes to project delays and budget overruns?

○ Yes
○ No



12. Do you think structured risk assessment improves hydropower project performance?

○ Yes

○ No

Section III: Risk Factor Assessment

The following is a list of key risk categories and their associated factors that influence hydropower projects. Please assess the level of impact each risk factor has on hydropower projects in Nepal by using the scoring system provided as:

1. Low Score = Low Risk
2. Medium Score = Medium Risk
3. High Score = High Risk

» A. Design Risks

1. To what extent are geological and hydrological investigations conducted thoroughly before finalizing the design?

○ Clearly defined and understood ○ Partially defined or unclear ○ Poorly defined and misunderstood

2. How appropriate and accurate are the dam design and tunnel alignment decisions based on field conditions?

○ Highly appropriate ○ Moderately appropriate ○ Inappropriate

3. To what degree do difficult topography and terrain impact design feasibility?

○ No impact ○ Moderate impact ○ Severe impact

4. How effectively is the design adapted to remote and logistically challenging site conditions?

○ Fully adapted ○ Partially adapted ○ Not adapted

» B. Management and Coordination Risks

1.To what extent are communication and coordination mechanisms clearly established among contractors, consultants, and local authorities?

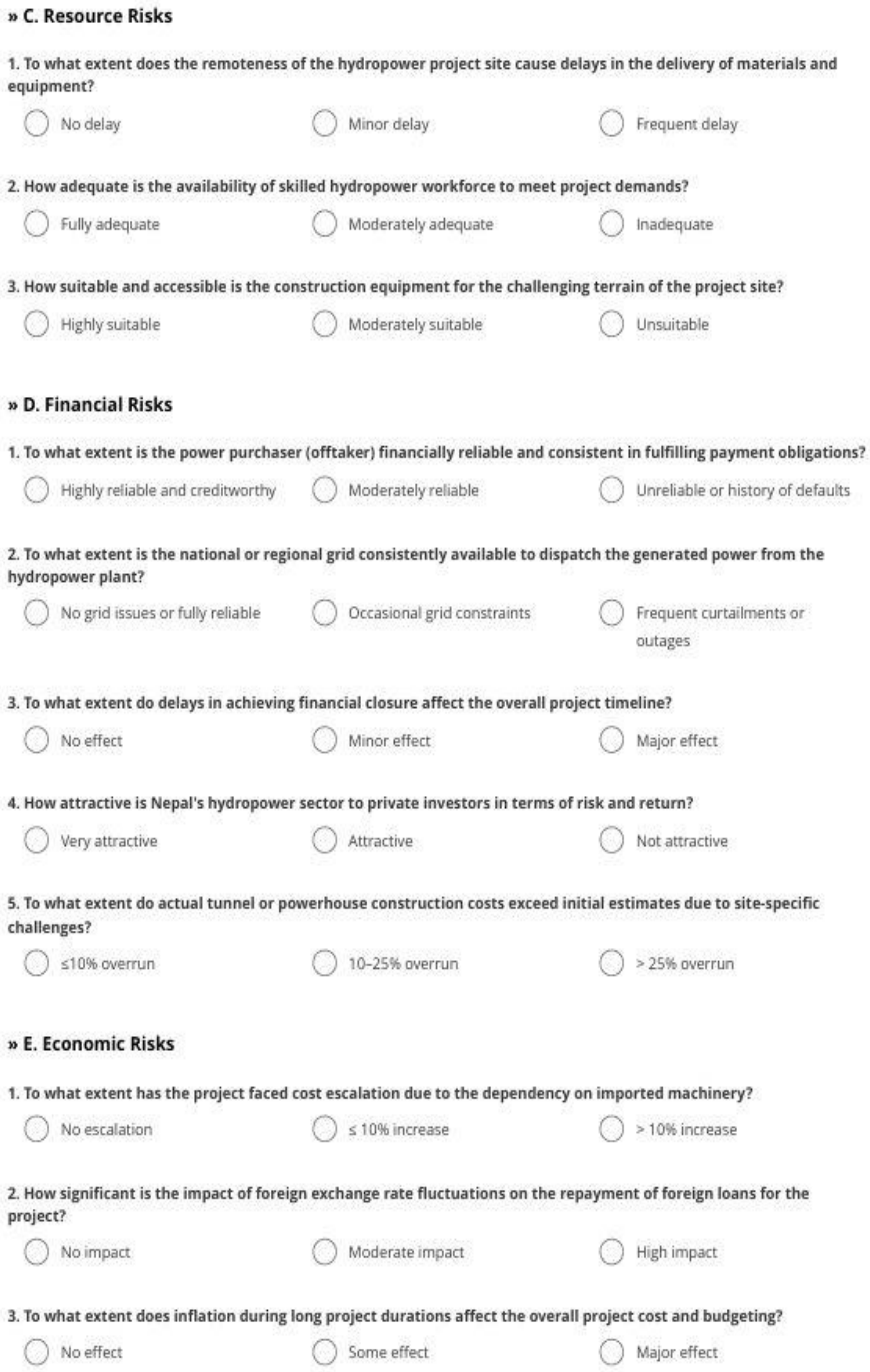
○ Fully established ○ Partially established ○ Poorly established

2.How experienced is the project management team in handling the technical complexity of hydropower projects?

○ >5 years ○ ≤5 years ○ Fresher

3.How well are project objectives and progress communicated to all stakeholders including local communities?

○ Well communicated ○ Partially communicated ○ Poorly communicated



» C. Resource Risks

1. To what extent does the remoteness of the hydropower project site cause delays in the delivery of materials and equipment?

○ No delay ○ Minor delay ○ Frequent delay

2. How adequate is the availability of skilled hydropower workforce to meet project demands?

○ Fully adequate ○ Moderately adequate ○ Inadequate

3. How suitable and accessible is the construction equipment for the challenging terrain of the project site?

○ Highly suitable ○ Moderately suitable ○ Unsuitable

» D. Financial Risks

1. To what extent is the power purchaser (offtaker) financially reliable and consistent in fulfilling payment obligations?

○ Highly reliable and creditworthy ○ Moderately reliable ○ Unreliable or history of defaults

2. To what extent is the national or regional grid consistently available to dispatch the generated power from the hydropower plant?

○ No grid issues or fully reliable ○ Occasional grid constraints ○ Frequent curtailments or outages

3. To what extent do delays in achieving financial closure affect the overall project timeline?

○ No effect ○ Minor effect ○ Major effect

4. How attractive is Nepal's hydropower sector to private investors in terms of risk and return?

○ Very attractive ○ Attractive ○ Not attractive

5. To what extent do actual tunnel or powerhouse construction costs exceed initial estimates due to site-specific challenges?

○ ≤10% overrun ○ 10–25% overrun ○ > 25% overrun

» E. Economic Risks

1. To what extent has the project faced cost escalation due to the dependency on imported machinery?

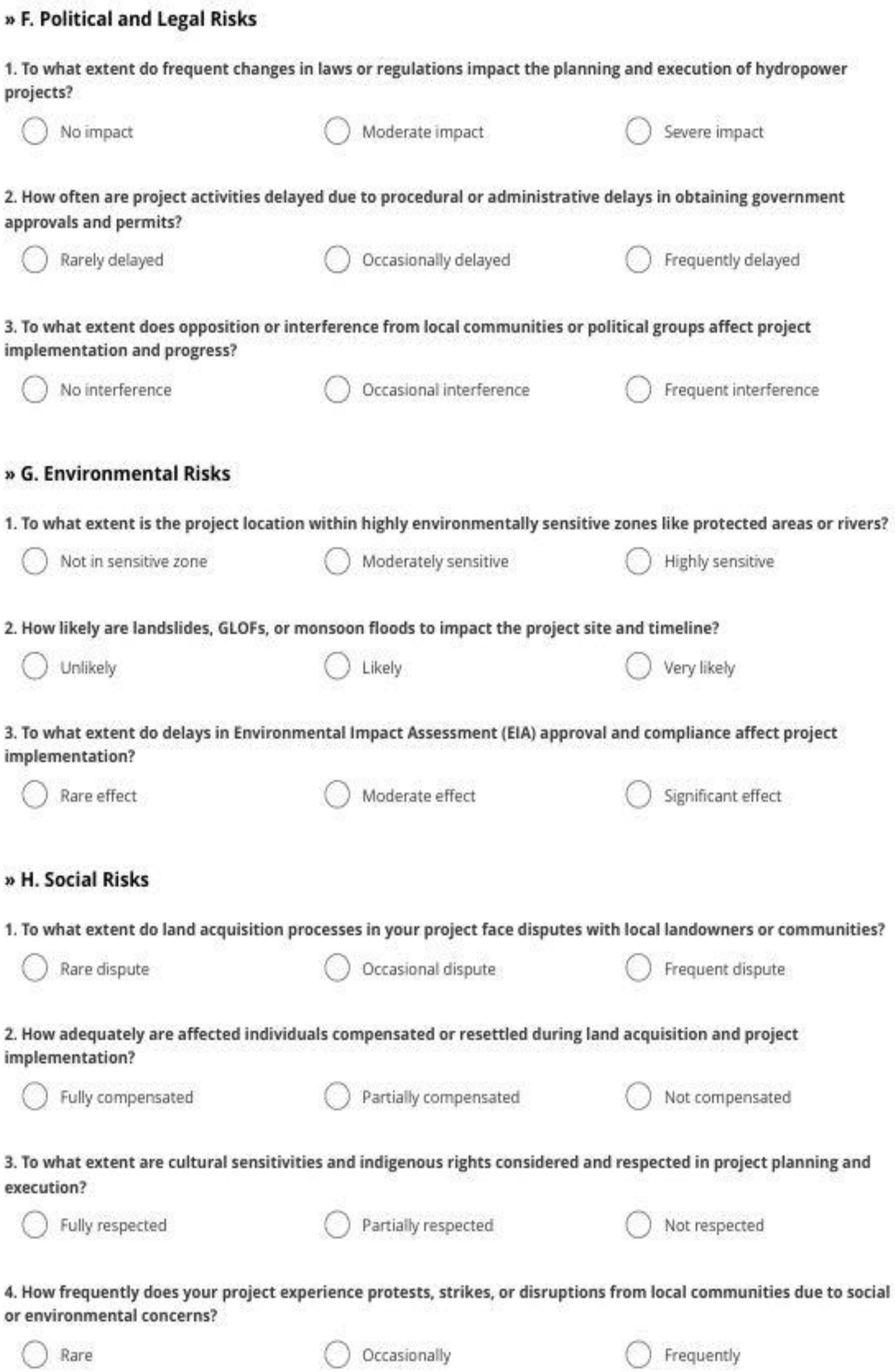
○ No escalation ○ ≤ 10% increase ○ > 10% increase

2. How significant is the impact of foreign exchange rate fluctuations on the repayment of foreign loans for the project?

○ No impact ○ Moderate impact ○ High impact

3. To what extent does inflation during long project durations affect the overall project cost and budgeting?

○ No effect ○ Some effect ○ Major effect



» F. Political and Legal Risks

1. To what extent do frequent changes in laws or regulations impact the planning and execution of hydropower projects?

○ No impact ○ Moderate impact ○ Severe impact

2. How often are project activities delayed due to procedural or administrative delays in obtaining government approvals and permits?

○ Rarely delayed ○ Occasionally delayed ○ Frequently delayed

3. To what extent does opposition or interference from local communities or political groups affect project implementation and progress?

○ No interference ○ Occasional interference ○ Frequent interference

» G. Environmental Risks

1. To what extent is the project location within highly environmentally sensitive zones like protected areas or rivers?

○ Not in sensitive zone ○ Moderately sensitive ○ Highly sensitive

2. How likely are landslides, GLOFs, or monsoon floods to impact the project site and timeline?

○ Unlikely ○ Likely ○ Very likely

3. To what extent do delays in Environmental Impact Assessment (EIA) approval and compliance affect project implementation?

○ Rare effect ○ Moderate effect ○ Significant effect

» H. Social Risks

1. To what extent do land acquisition processes in your project face disputes with local landowners or communities?

○ Rare dispute ○ Occasional dispute ○ Frequent dispute

2. How adequately are affected individuals compensated or resettled during land acquisition and project implementation?

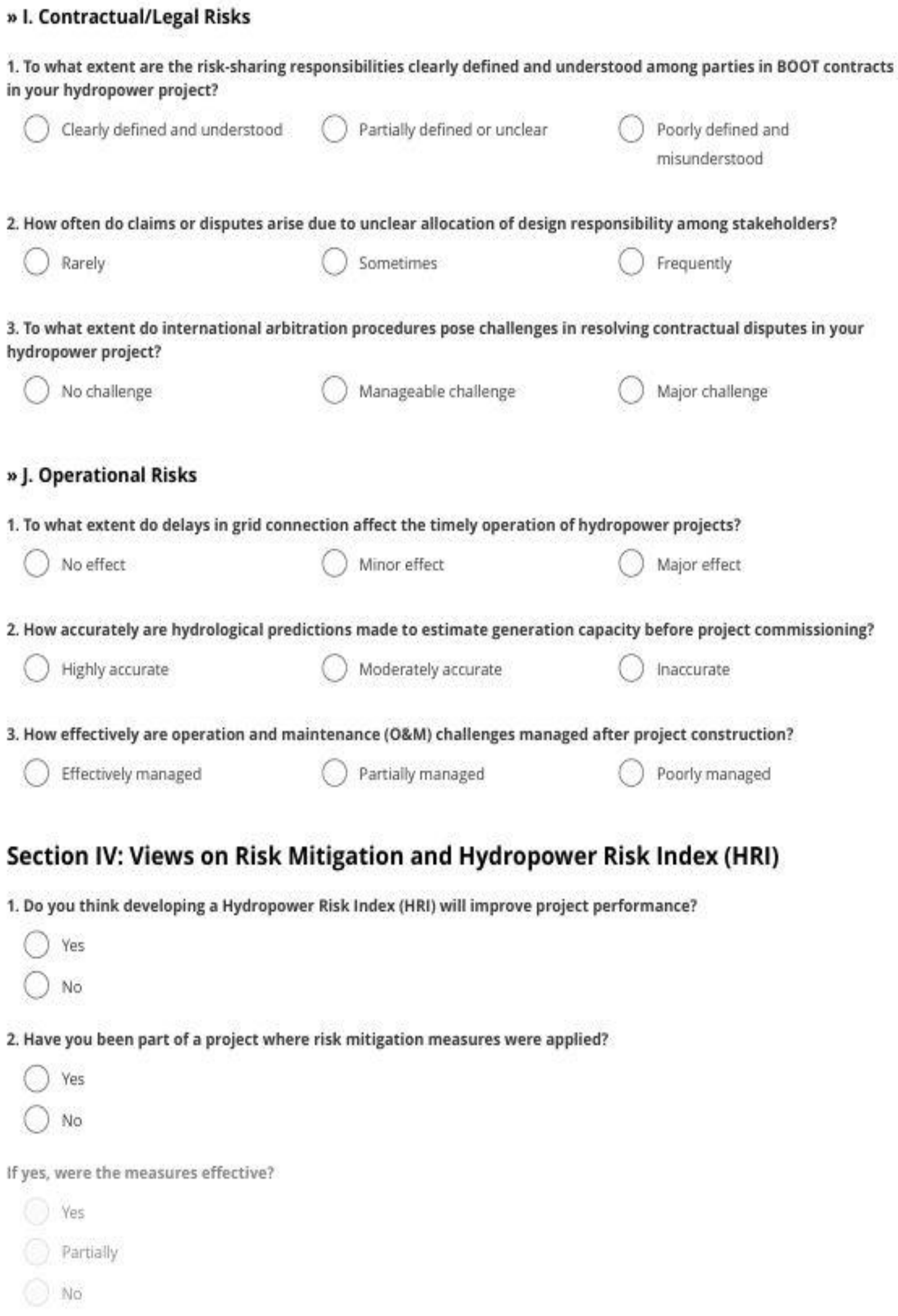
○ Fully compensated ○ Partially compensated ○ Not compensated

3. To what extent are cultural sensitivities and indigenous rights considered and respected in project planning and execution?

○ Fully respected ○ Partially respected ○ Not respected

4. How frequently does your project experience protests, strikes, or disruptions from local communities due to social or environmental concerns?

○ Rare ○ Occasionally ○ Frequently



» I. Contractual/Legal Risks

1. To what extent are the risk-sharing responsibilities clearly defined and understood among parties in BOOT contracts in your hydropower project?

○ Clearly defined and understood ○ Partially defined or unclear ○ Poorly defined and misunderstood

2. How often do claims or disputes arise due to unclear allocation of design responsibility among stakeholders?

○ Rarely ○ Sometimes ○ Frequently

3. To what extent do international arbitration procedures pose challenges in resolving contractual disputes in your hydropower project?

○ No challenge ○ Manageable challenge ○ Major challenge

» J. Operational Risks

1. To what extent do delays in grid connection affect the timely operation of hydropower projects?

○ No effect ○ Minor effect ○ Major effect

2. How accurately are hydrological predictions made to estimate generation capacity before project commissioning?

○ Highly accurate ○ Moderately accurate ○ Inaccurate

3. How effectively are operation and maintenance (O&M) challenges managed after project construction?

○ Effectively managed ○ Partially managed ○ Poorly managed

Section IV: Views on Risk Mitigation and Hydropower Risk Index (HRI)

1. Do you think developing a Hydropower Risk Index (HRI) will improve project performance?

○ Yes
○ No

2. Have you been part of a project where risk mitigation measures were applied?

○ Yes
○ No

If yes, were the measures effective?

○ Yes
○ Partially
○ No

3. Which risk categories have the highest impact on hydropower projects?

- ☐ Design
- ☐ Management and Coordination
- ☐ Resources
- ☐ Financial
- ☐ Economic
- ☐ Political and Legal
- ☐ Environmental
- ☐ Social
- ☐ Contractual and Legal
- ☐ Operational

4. What mitigation strategies do you think are most effective for managing these risk categories?

____

5. Any additional comments on risk management in hydropower projects?

____

APPENDIX 2: Demographic Profile of Respondents

a) Gender

The survey respondents comprised 93 males and 9 females, indicating that male participants represented the majority of 91.18% while females accounted for 8.82%. This shows a higher level of participation from male professionals in the hydropower sector.

Table A2. 1 Gender Distribution of Respondents

Gender		
	Number	Percent
Male	93	91.18
Female	9	8.82
Total	102	100.0

b) Working Sector

In terms of the sector respondents are employed in, 53 work in the government sector, 45 in the private sector, and 4 have experience in both sectors. This distribution suggests a slightly higher representation from the government sector, while small portion of respondents has experience across both sectors, providing a broad understanding of organizational contexts.

Table A2. 2 Respondents' Working Sector

Which sector do you work in?		
	Number	Percent
Government	53	51.96
Private	45	44.12
Both	4	3.92
Total	102	100.0

c) Parties

When asked about their employers, 63 respondents work for clients, 18 for contractors, and 32 for consultants. The distribution across these categories indicates that the survey captured perspectives from all major stakeholders involved in hydropower projects, ensuring diverse insights into project risks.

Table A2. 3 Respondents' Working Parties

Who do you work for?		
	Number	Percent
Client	63	55.75

Contractor	18	15.93
Consultant	32	28.32
Total	102	100.0

d) Job Role

Regarding professional roles, 9 respondents are project managers, 60 are engineers or architects, 13 are site engineers, 9 are project engineers, and 11 hold other positions. The majority being engineers/architects indicates that the responses largely reflect technical expertise, while project managers and other roles provide additional management and oversight perspectives.

Table A2. 4 Respondents' Job Role

What is your job role?		
	Number	Percent
Project Manager	9	8.82
Engineer/ Architect	60	58.82
Site Engineer	13	12.75
Project Engineer	9	8.82
Others	11	10.78
Total	102	100.0

e) Scale of Projects

Regarding the scale of hydropower projects respondents are involved in, 34 work on small projects (<10 MW), 23 on medium projects (10–100 MW), 8 on large projects (>100 MW), and 48 on other types. This indicates that most respondents have experience with the “Others” category which includes respondents engaged in micro or hybrid hydropower, feasibility and rehabilitation works or those involved across multiple project sizes, including consultants and regulatory roles. It represents diverse project types beyond the defined capacity ranges, followed by small, medium and large-scale projects, reflecting significant exposure to substantial hydropower developments.

Table A2. 5 Scale of Projects

What types of hydropower projects are you involved in?		
	Number	Percent
Small hydropower (<10 MW)	34	30.09
Medium hydropower (10–100 MW)	23	20.35

Large hydropower (>100 MW)	8	7.08
Others	48	42.48
Total	102	100.0

f) Funding Types of Hydropower Projects

In terms of project funding, 64 respondents have worked on government-funded projects, 40 on privately funded projects, and 22 on donor-funded projects (e.g., ADB, WB, JICA). The even distribution across funding types suggests that respondents have diverse experience with various financial and institutional arrangements in hydropower development.

Table A2. 6 Funding Types of Hydropower Projects

What types of projects have you worked for?		
	Number	Percent
Government Funded	64	50.79
Private	40	31.75
Donor Funded (ADB, WB, JICA, etc.)	22	17.46
Total	102	100.0

g) Involvement in Hydropower Projects

When asked about the number of hydropower projects they have participated in, 88 respondents reported involvement in 1–5 projects, 9 in 6–10 projects, 1 in 11–20 projects, and 4 in more than 21 projects. This shows that most respondents have small experiences in hydropower projects, while only smaller groups have extensive involvement in multiple projects, providing a range of practical perspectives.

Table A2. 7 Involvement in Hydropower Projects

How many hydropower projects have you been involved in?		
	Number	Percent
1–5	88	86.27
6–10	9	8.82
11–20	1	0.98
21 or more	4	3.92
Total	102	100.0

APPENDIX 3: Detailed Calculation of Chi-Square Test Analysis of Risk Assessment

Table A3. 1 Chi-Square Observed Frequency Table for Design Risk Factors

Design Risk Factors	**Low**	**Medium**	**High**	**Total**
Adequacy of geological and hydrological investigations	44	56	2	**102**
Appropriateness of dam and tunnel design	44	56	2	**102**
Impact of difficult topography on design feasibility	5	28	69	**102**
Adaptability of design to remote conditions	27	68	7	**102**
Total	**120**	**208**	**80**	**408**

Step 1: Expected frequencies
Since each row total = 102 and grand total = 408:

- Expected (Low) = $102 \times 120/408 = 30$
- Expected (Medium) = $102 \times 208/408 = 52$
- Expected (High) = $102 \times 80/408 = 20$

Step 2: Chi-square statistic

$$\chi^2 = \sum \frac{(O-E)^2}{E} \approx 211.7$$

Step 3: Degrees of freedom

$$df = (4-1)(3-1) = 6$$

Step 4: Decision (95% confidence level)

- Critical value at $\alpha = 0.05, df = 6 \approx 12.59$
- Calculated $\chi^2 = 211.7 \gg 12.59$
- p-value < 0.001

Interpretation

There is a statistically significant association between risk factors and risk levels at the 95% confidence interval.

Table A3. 2 Chi-Square Observed Frequency Table for Management & Coordination Risk Factors

Management & Coordination Risk Factors	**Low**	**Medium**	**High**	**Total**
Communication and coordination among parties	33	54	15	**102**
Experience of project management team	66	28	8	**102**
Communication of objectives and progress to stakeholders	34	55	13	**102**
Total	**133**	**137**	**36**	**306**

Step 1: Expected frequencies
Using row total = 102 and grand total = 306:

- Expected (Low) = $102 \times 133/306 \approx 44.33$
- Expected (Medium) = $102 \times 137/306 \approx 45.67$
- Expected (High) = $102 \times 36/306 = 12$

Step 2: Chi-square statistic

$$\chi^2 = \sum \frac{(O - E)^2}{E} \approx 33.22$$

Step 3: Degrees of freedom

$$df = (3 - 1)(3 - 1) = 4$$

Step 4: Decision (95% confidence level)

- Critical value at $\alpha = 0.05, df = 4 \approx 9.49$
- Calculated $\chi^2 = 33.22 \gg 9.49$
- p-value < 0.001

Interpretation

There is a statistically significant association between risk factors and risk levels at the 95% confidence interval.

Table A3. 3 Chi-Square Observed Frequency Table for Resource Risk Factors

Resource Risk Factors	**Low**	**Medium**	**High**	**Total**
Delay due to remoteness of project sites	10	38	54	**102**
Availability of skilled hydropower workforce	31	57	14	**102**
Suitability of equipment for terrain	24	61	17	**102**
Total	**65**	**156**	**85**	**306**

Step 1: Expected frequencies
Row total = 102, Grand total = 306:

- Expected (Low) = $102 \times 65/306 \approx 21.67$
- Expected (Medium) = $102 \times 156/306 = 52$
- Expected (High) = $102 \times 85/306 \approx 28.33$

Step 2: Chi-square statistic

$$\chi^2 = \sum \frac{(O-E)^2}{E} \approx 60.36$$

Step 3: Degrees of freedom

$$df = (3-1)(3-1) = 4$$

Step 4: Decision (95% confidence level)

- Critical value at $\alpha = 0.05, df = 4 \approx 9.49$
- Calculated $\chi^2 = 60.36 \gg 9.49$
- p-value < 0.001

Interpretation

There is a statistically significant association between risk factors and risk levels at the 95% confidence interval.

Table A3. 4 Chi-Square Observed Frequency Table for Financial Risk Factors

Financial Risk Factors	Low	Medium	High	Total
Reliability of power purchaser	34	59	9	**102**
Grid availability for power dispatch	17	61	24	**102**
Delay in financial closure	4	36	62	**102**
Attractiveness of hydropower to investors	30	59	13	**102**
Construction cost overrun	18	62	22	**102**
Total	**103**	**277**	**130**	**510**

Step 1: Expected frequencies
Row total = 102, Grand total = 510:

- Expected (Low) = $102 \times 103/510 = 20.6$
- Expected (Medium) = $102 \times 277/510 = 55.4$
- Expected (High) = $102 \times 130/510 = 26.0$

Step 2: Chi-square statistic

$$\chi^2 = \sum \frac{(O-E)^2}{E} \approx 135.26$$

Step 3: Degrees of freedom

$$df = (5-1)(3-1) = 8$$

Step 4: Decision (95% confidence level)

- Critical value at $\alpha = 0.05, df = 8 \approx 15.51$
- Calculated $\chi^2 = 135.26 \gg 15.51$
- p-value < 0.001

Interpretation

There is a statistically significant association between risk factors and risk levels at the 95% confidence interval.

Table A3. 5 Chi-Square Observed Frequency Table for Economic Risk Factors

Economic Risk Factors	Low	Medium	High	Total
Cost escalation due to imports	10	49	43	**102**
Impact of foreign exchange fluctuations	3	60	39	**102**
Effect of inflation on project budgeting	5	43	54	**102**
Total	**18**	**152**	**136**	**306**

Step 1: Expected frequencies
Row total = 102, Grand total = 306:

- Expected (Low) = $102 \times 18/306 = 6$
- Expected (Medium) = $102 \times 152/306 \approx 50.67$
- Expected (High) = $102 \times 136/306 \approx 45.33$

Step 2: Chi-square statistic

$$\chi^2 = \sum \frac{(O-E)^2}{E} \approx 16.03$$

Step 3: Degrees of freedom

$$df = (3-1)(3-1) = 4$$

Step 4: Decision (95% confidence level)

- Critical value at $\alpha = 0.05, df = 4 \approx 9.49$
- Calculated $\chi^2 = 16.03 > 9.49$
- p-value < 0.01

Interpretation

There is a statistically significant association between financial risk factors and risk levels at the 95% confidence interval.

Table A3. 6 Chi-Square Observed Frequency Table for Political & Legal Risk Factors

Political & Legal Risk Factors	**Low**	**Medium**	**High**	**Total**
Changes in laws/regulations	5	51	46	**102**
Administrative delays in government approvals	11	44	47	**102**
Interference from local groups or politics	6	59	37	**102**
Total	**22**	**154**	**130**	**306**

Step 1: Expected frequencies
Row total = 102, Grand total = 306:

- Expected (Low) = $102 \times 22/306 \approx 7.33$
- Expected (Medium) = $102 \times 154/306 \approx 51.33$
- Expected (High) = $102 \times 130/306 \approx 43.33$

Step 2: Chi-square statistic

$$\chi^2 = \sum \frac{(O-E)^2}{E} \approx 5.91$$

Step 3: Degrees of freedom

$$df = (3-1)(3-1) = 4$$

Step 4: Decision (95% confidence level)

- Critical value at $\alpha = 0.05, df = 4 \approx 9.49$
- Calculated $\chi^2 = 5.91 < 9.49$
- p-value > 0.05

Interpretation

There is no statistically significant association between regulatory/political risk factors and risk levels at the 95% confidence interval. This means the risk levels (low, medium, high) are fairly evenly distributed across these factors, and no single factor stands out as disproportionately high risk compared to others.

Table A3. 7 Chi-Square Observed Frequency Table for Environmental Risk Factors

Environmental Risk Factors	**Low**	**Medium**	**High**	**Total**

Location in environmentally sensitive zone	7	49	46	**102**
Impact of natural hazards (landslides, GLOFs, floods)	10	45	47	**102**
Delays in EIA approval/compliance	5	47	50	**102**
Total	**22**	**141**	**143**	**306**

Step 1: Expected frequencies
Row total = 102, Grand total = 306:

- Expected (Low) = $102 \times 22/306 \approx 7.33$
- Expected (Medium) = $102 \times 141/306 = 47.0$
- Expected (High) = $102 \times 143/306 \approx 47.67$

Step 2: Chi-square statistic

$$\chi^2 = \sum \frac{(O - E)^2}{E} \approx 1.28$$

Step 3: Degrees of freedom

$$df = (3 - 1)(3 - 1) = 4$$

Step 4: Decision (95% confidence level)

- Critical value at $\alpha = 0.05, df = 4 \approx 9.49$
- Calculated $\chi^2 = 1.28 < 9.49$
- p-value > 0.05

Interpretation

There is no statistically significant association between environmental risk factors and risk levels at the 95% confidence interval. The distribution of low, medium, and high risks is fairly uniform across all factors, indicating that environmental risks contribute similarly across categories without any single dominant high-risk factor.

Table A3. 8 Chi-Square Observed Frequency Table for Social Risk Factors

Social Risk Factors	**Low**	**Medium**	**High**	**Total**
Land acquisition disputes	8	50	44	**102**
Adequacy of compensation/resettlement	25	67	10	**102**
Consideration of cultural and indigenous rights	24	69	9	**102**
Frequency of local protests and strikes	20	60	22	**102**
Total	**77**	**246**	**85**	**408**

Step 1: Expected frequencies
Row total = 102, Grand total = 408:

- Expected (Low) = $102 \times 77/408 \approx 19.25$
- Expected (Medium) = $102 \times 246/408 \approx 61.5$
- Expected (High) = $102 \times 85/408 \approx 21.25$

Step 2: Chi-square statistic

$$\chi^2 = \sum \frac{(O - E)^2}{E} \approx 32.94$$

Step 3: Degrees of freedom

$$df = (4 - 1)(3 - 1) = 6$$

Step 4: Decision (95% confidence level)

- Critical value at $\alpha = 0.05, df = 6 \approx 12.59$
- Calculated $\chi^2 = 32.94 \gg 12.59$
- p-value < 0.001

Interpretation

There is a statistically significant association between social risk factors and risk levels at the 95% confidence interval.

Table A3. 9 Chi-Square Observed Frequency Table for Contractual/Legal Risk Factors

Contractual/Legal Risk Factors	**Low**	**Medium**	**High**	**Total**
Clarity of risk-sharing responsibilities	33	56	13	**102**
Frequency of design-related disputes	13	65	24	**102**
Challenges in arbitration procedures	13	72	17	**102**
Total	**59**	**193**	**54**	**306**

Step 1: Expected frequencies
Grand total = 306
Each row total = 102
Column totals:

- Low = 59
- Medium = 193
- High = 54

Expected frequencies per row (same for all 3 rows):

- Expected (Low) = 102 × 59 / 306 = 19.67
- Expected (Medium) = 102 × 193 / 306 = 64.33
- Expected (High) = 102 × 54 / 306 = 18

So, expected values for each row:
Low = 19.67, Medium = 64.33, High = 18

Step 2: Chi-square statistic

$$\chi^2 = \sum\frac{(O-E)^2}{E} \approx 26.42$$

Step 3: Degrees of freedom
df = (3 − 1)(3 − 1) = 4

Step 4: Decision (95% confidence level)

- Critical value at α = 0.05, df = 4 ≈ 9.488
- Calculated $\chi^2 = 26.42 > 9.488$
- p-value < 0.001

Interpretation

There is a statistically significant association between dispute-related risk factors and risk levels at the 95% confidence interval.

Table A3. 10 Chi-Square Observed Frequency Table for Operational Risk Factors

Operational Risk Factors	**Low**	**Medium**	**High**	**Total**
Delays in grid connection	9	59	34	**102**
Accuracy of hydrological predictions	24	70	8	**102**
Effectiveness of O&M management	32	58	12	**102**
Total	**65**	**187**	**54**	**306**

Step 1: Expected frequencies
Grand total = 306
Each row total = 102
Expected values per row:

- Expected (Low) = 102 × 65 / 306 = 21.67
- Expected (Medium) = 102 × 187 / 306 = 62.33
- Expected (High) = 102 × 54 / 306 = 18

So, expected frequencies for each row are:
Low = 21.67, Medium = 62.33, High = 18

Step 2: Chi-square statistic

$$\chi^2 = \sum \frac{(O - E)^2}{E} \approx 35.79$$

Step 3: Degrees of freedom

df = (3 − 1)(3 − 1) = 4

Step 4: Decision (95% confidence level)

- Critical value at $\alpha = 0.05$, df = 4 ≈ 9.488
- Calculated $\chi^2 = 35.79 \gg 9.488$
- p-value < 0.001

Interpretation
There is a statistically significant association between risk factors and risk levels at the 95% confidence interval

APPENDIX 4: Calculation of Base and Adjusted HRI Scores under Weight Variations for Sensitivity Analysis

Table A4. 1 Calculation of Base and Adjusted HRI Scores under Weight Variations

Avg. rating of risk factors (X_i)	% composition of risks	Weightage of risk factors = X_i*% composition	Base HRI score	Max. rating of risk factors (X_i)	% composition of risks	Max. weightage of risk factors = X_i*% composition	Max. value of HRI score
44.4	0.2	8.88	0.3867	102	0.2	20.4	1.1493
30	0.2	6	0.1766	102	0.2	20.4	1.1493
86.8	0.2	17.36	1.4781	102	0.2	20.4	1.1493
41.65	0.2	8.33	0.3403	102	0.2	20.4	1.1493
62.07	0.1	6.207	0.1890	102	0.1	10.2	0.2873
40.8	0.1	4.08	0.0816	102	0.1	10.2	0.2873
49	0.1	4.9	0.1178	102	0.1	10.2	0.2873
82.76	0.1	8.276	0.3359	102	0.1	10.2	0.2873
39.9	0.1	3.99	0.0781	102	0.1	10.2	0.2873
43.8	0.1	4.38	0.0941	102	0.1	10.2	0.2873
38.5	0.15	5.775	0.1636	102	0.15	15.3	0.6465
64	0.15	9.6	0.4520	102	0.15	15.3	0.6465
76.4	0.15	11.46	0.6441	102	0.15	15.3	0.6465
30.7	0.15	4.605	0.1040	102	0.15	15.3	0.6465
70.8	0.15	10.62	0.5532	102	0.15	15.3	0.6465
74.4	0.05	3.72	0.0679	102	0.05	5.1	0.0718
69	0.05	3.45	0.0584	102	0.05	5.1	0.0718
75.5	0.05	3.775	0.0699	102	0.05	5.1	0.0718
71.5	0.1	7.15	0.2507	102	0.1	10.2	0.2873
75.6	0.1	7.56	0.2803	102	0.1	10.2	0.2873
78.51	0.1	7.851	0.3023	102	0.1	10.2	0.2873
75.4	0.1	7.54	0.2788	102	0.1	10.2	0.2873
70.5	0.1	7.05	0.2438	102	0.1	10.2	0.2873
74.5	0.1	7.45	0.2722	102	0.1	10.2	0.2873
70.6	0.05	3.53	0.0611	102	0.05	5.1	0.0718
43.5	0.05	2.175	0.0232	102	0.05	5.1	0.0718
38.5	0.05	1.925	0.0182	102	0.05	5.1	0.0718
50	0.05	2.5	0.0307	102	0.05	5.1	0.0718
53.2	0.05	2.66	0.0347	102	0.05	5.1	0.0718
57.8	0.05	2.89	0.0410	102	0.05	5.1	0.0718
56.9	0.05	2.845	0.0397	102	0.05	5.1	0.0718
64.4	0.1	6.44	0.2034	102	0.1	10.2	0.2873
36	0.1	3.6	0.0636	102	0.1	10.2	0.2873
53.2	0.1	5.32	0.1388	102	0.1	10.2	0.2873

Total	**3.55**	**203.894**	**7.6736**	**Total**	**3.55**	**362.1**	**12.8577**
		Relative HRI =	**59.68 %**			**Max. value of HRI =**	**12.8577**

After +5% increase in x1				**After +10% increase in x1**			
Avg. rating of risk factors (Xi)	**% composition of risks**	**Weightage of risk factors = X_i*% composition**	**HRI score**	**Avg. rating of risk factors (X_i)**	**% composition of risks**	**Weightage of risk factors = X_i***	**HRI score**
44.4	0.2	8.88	0.3843	44.4	0.2	8.88	0.3827
30	0.2	6	0.1755	30	0.2	6	0.1747
91.14	0.2	18.228	1.6194	95.48	0.2	19.096	1.7698
41.65	0.2	8.33	0.3382	41.65	0.2	8.33	0.3368
62.07	0.1	6.207	0.1878	62.07	0.1	6.207	0.1870
40.8	0.1	4.08	0.0811	40.8	0.1	4.08	0.0808
49	0.1	4.9	0.1170	49	0.1	4.9	0.1165
86.898	0.1	8.6898	0.3680	86.898	0.1	8.6898	0.3665
39.9	0.1	3.99	0.0776	39.9	0.1	3.99	0.0773
43.8	0.1	4.38	0.0935	43.8	0.1	4.38	0.0931
38.5	0.15	5.775	0.1625	38.5	0.15	5.775	0.1619
64	0.15	9.6	0.4492	64	0.15	9.6	0.4473
76.4	0.15	11.46	0.6401	76.4	0.15	11.46	0.6374
30.7	0.15	4.605	0.1034	30.7	0.15	4.605	0.1029
70.8	0.15	10.62	0.5497	70.8	0.15	10.62	0.5474
74.4	0.05	3.72	0.0674	74.4	0.05	3.72	0.0672
69	0.05	3.45	0.0580	69	0.05	3.45	0.0578
75.5	0.05	3.775	0.0695	75.5	0.05	3.775	0.0692
71.5	0.1	7.15	0.2492	71.5	0.1	7.15	0.2481
75.6	0.1	7.56	0.2786	75.6	0.1	7.56	0.2774
78.51	0.1	7.851	0.3004	78.51	0.1	7.851	0.2992
75.4	0.1	7.54	0.2771	75.4	0.1	7.54	0.2759
70.5	0.1	7.05	0.2422	70.5	0.1	7.05	0.2412
74.5	0.1	7.45	0.2705	74.5	0.1	7.45	0.2694
70.6	0.05	3.53	0.0607	70.6	0.05	3.53	0.0605
43.5	0.05	2.175	0.0231	43.5	0.05	2.175	0.0230
38.5	0.05	1.925	0.0181	38.5	0.05	1.925	0.0180
50	0.05	2.5	0.0305	50	0.05	2.5	0.0303
53.2	0.05	2.66	0.0345	53.2	0.05	2.66	0.0343
57.8	0.05	2.89	0.0407	57.8	0.05	2.89	0.0405
56.9	0.05	2.845	0.0394	56.9	0.05	2.845	0.0393
64.4	0.1	6.44	0.2021	64.4	0.1	6.44	0.2013
36	0.1	3.6	0.0632	36	0.1	3.6	0.0629
53.2	0.1	5.32	0.1379	53.2	0.1	5.32	0.1374

Total	**3.55**	**205.1758**	**7.8104**	**Total**	**3.55**	**206.0438**	**7.9347**
		Relative HRI =	**60.74 %**			**Relative HRI =**	**61.71%**
After +15% increase in x1				**After +20% increase in x1**			
Avg. rating of risk factors (Xi)	**% composition of risks**	**Weightage of risk factors = X_i*% composition**	**HRI score**	**Avg. rating of risk factors (X_i)**	**% composition of risks**	**Weightage of risk factors = X_i***	**HRI score**
44.4	0.2	8.88	0.3811	44.4	0.2	8.88	0.3795
30	0.2	6	0.1740	30	0.2	6	0.1733
99.82	0.2	19.964	1.9262	104.16	0.2	20.832	2.0886
41.65	0.2	8.33	0.3354	41.65	0.2	8.33	0.3340
62.07	0.1	6.207	0.1862	62.07	0.1	6.207	0.1854
40.8	0.1	4.08	0.0805	40.8	0.1	4.08	0.0801
49	0.1	4.9	0.1160	49	0.1	4.9	0.1156
86.898	0.1	8.6898	0.3650	86.898	0.1	8.6898	0.3634
39.9	0.1	3.99	0.0769	39.9	0.1	3.99	0.0766
43.8	0.1	4.38	0.0927	43.8	0.1	4.38	0.0923
38.5	0.15	5.775	0.1612	38.5	0.15	5.775	0.1605
64	0.15	9.6	0.4454	64	0.15	9.6	0.4435
76.4	0.15	11.46	0.6347	76.4	0.15	11.46	0.6321
30.7	0.15	4.605	0.1025	30.7	0.15	4.605	0.1021
70.8	0.15	10.62	0.5451	70.8	0.15	10.62	0.5428
74.4	0.05	3.72	0.0669	74.4	0.05	3.72	0.0666
69	0.05	3.45	0.0575	69	0.05	3.45	0.0573
75.5	0.05	3.775	0.0689	75.5	0.05	3.775	0.0686
71.5	0.1	7.15	0.2471	71.5	0.1	7.15	0.2460
75.6	0.1	7.56	0.2762	75.6	0.1	7.56	0.2751
78.51	0.1	7.851	0.2979	78.51	0.1	7.851	0.2967
75.4	0.1	7.54	0.2748	75.4	0.1	7.54	0.2736
70.5	0.1	7.05	0.2402	70.5	0.1	7.05	0.2392
74.5	0.1	7.45	0.2682	74.5	0.1	7.45	0.2671
70.6	0.05	3.53	0.0602	70.6	0.05	3.53	0.0600
43.5	0.05	2.175	0.0229	43.5	0.05	2.175	0.0228
38.5	0.05	1.925	0.0179	38.5	0.05	1.925	0.0178
50	0.05	2.5	0.0302	50	0.05	2.5	0.0301
53.2	0.05	2.66	0.0342	53.2	0.05	2.66	0.0341
57.8	0.05	2.89	0.0404	57.8	0.05	2.89	0.0402
56.9	0.05	2.845	0.0391	56.9	0.05	2.845	0.0390
64.4	0.1	6.44	0.2004	64.4	0.1	6.44	0.1996
36	0.1	3.6	0.0626	36	0.1	3.6	0.0624
53.2	0.1	5.32	0.1368	53.2	0.1	5.32	0.1362
Total	**3.55**	**206.9118**	**8.0653**	**Total**	**3.55**	**207.7798**	**8.2020**

		Relative HRI =	**62.73 %**			**Relative HRI =**	**63.79%**
After -5% increase in x1				**After -10% increase in x1**			
Avg. rating of risk factors (Xi)	**% composition of risks**	**Weightage of risk factors = X_i*% composition**	**HRI score**	**Avg. rating of risk factors (X_i)**	**% composition of risks**	**Weightage of risk factors = X_i***	**HRI score**
44.4	0.2	8.88	0.3876	44.4	0.2	8.88	0.3893
30	0.2	6	0.1770	30	0.2	6	0.1777
82.46	0.2	16.492	1.3369	78.12	0.2	15.624	1.2051
41.65	0.2	8.33	0.3411	41.65	0.2	8.33	0.3425
62.07	0.1	6.207	0.1894	62.07	0.1	6.207	0.1902
40.8	0.1	4.08	0.0818	40.8	0.1	4.08	0.0822
49	0.1	4.9	0.1180	49	0.1	4.9	0.1185
86.898	0.1	8.6898	0.3712	86.898	0.1	8.6898	0.3728
39.9	0.1	3.99	0.0783	39.9	0.1	3.99	0.0786
43.8	0.1	4.38	0.0943	43.8	0.1	4.38	0.0947
38.5	0.15	5.775	0.1639	38.5	0.15	5.775	0.1646
64	0.15	9.6	0.4530	64	0.15	9.6	0.4549
76.4	0.15	11.46	0.6456	76.4	0.15	11.46	0.6483
30.7	0.15	4.605	0.1042	30.7	0.15	4.605	0.1047
70.8	0.15	10.62	0.5544	70.8	0.15	10.62	0.5568
74.4	0.05	3.72	0.0680	74.4	0.05	3.72	0.0683
69	0.05	3.45	0.0585	69	0.05	3.45	0.0588
75.5	0.05	3.775	0.0700	75.5	0.05	3.775	0.0703
71.5	0.1	7.15	0.2513	71.5	0.1	7.15	0.2524
75.6	0.1	7.56	0.2809	75.6	0.1	7.56	0.2821
78.51	0.1	7.851	0.3030	78.51	0.1	7.851	0.3043
75.4	0.1	7.54	0.2795	75.4	0.1	7.54	0.2806
70.5	0.1	7.05	0.2443	70.5	0.1	7.05	0.2454
74.5	0.1	7.45	0.2728	74.5	0.1	7.45	0.2740
70.6	0.05	3.53	0.0613	70.6	0.05	3.53	0.0615
43.5	0.05	2.175	0.0233	43.5	0.05	2.175	0.0234
38.5	0.05	1.925	0.0182	38.5	0.05	1.925	0.0183
50	0.05	2.5	0.0307	50	0.05	2.5	0.0309
53.2	0.05	2.66	0.0348	53.2	0.05	2.66	0.0349
57.8	0.05	2.89	0.0411	57.8	0.05	2.89	0.0412
56.9	0.05	2.845	0.0398	56.9	0.05	2.845	0.0400
64.4	0.1	6.44	0.2039	64.4	0.1	6.44	0.2047
36	0.1	3.6	0.0637	36	0.1	3.6	0.0640
53.2	0.1	5.32	0.1391	53.2	0.1	5.32	0.1397
Total	**3.55**	**203.4398**	**7.5808**	**Total**	**3.55**	**202.5718**	**7.4756**

		Relative HRI =	**58.96 %**			**Relative HRI =**	**58.14%**
After -15% increase in x1				**After -20% increase in x1**			
Avg. rating of risk factors (Xi)	**% composition of risks**	**Weightage of risk factors = X_i*% composition**	**HRI score**	**Avg. rating of risk factors (X_i)**	**% composition of risks**	**Weightage of risk factors = X_i***	**HRI score**
44.4	0.2	8.88	0.3909	44.4	0.2	8.88	0.3926
30	0.2	6	0.1785	30	0.2	6	0.1793
73.78	0.2	14.756	1.0795	69.44	0.2	13.888	0.9604
41.65	0.2	8.33	0.3440	41.65	0.2	8.33	0.3455
62.07	0.1	6.207	0.1910	62.07	0.1	6.207	0.1918
40.8	0.1	4.08	0.0825	40.8	0.1	4.08	0.0829
49	0.1	4.9	0.1190	49	0.1	4.9	0.1196
86.898	0.1	8.6898	0.3744	86.898	0.1	8.6898	0.3760
39.9	0.1	3.99	0.0789	39.9	0.1	3.99	0.0793
43.8	0.1	4.38	0.0951	43.8	0.1	4.38	0.0955
38.5	0.15	5.775	0.1653	38.5	0.15	5.775	0.1661
64	0.15	9.6	0.4569	64	0.15	9.6	0.4589
76.4	0.15	11.46	0.6511	76.4	0.15	11.46	0.6539
30.7	0.15	4.605	0.1051	30.7	0.15	4.605	0.1056
70.8	0.15	10.62	0.5592	70.8	0.15	10.62	0.5616
74.4	0.05	3.72	0.0686	74.4	0.05	3.72	0.0689
69	0.05	3.45	0.0590	69	0.05	3.45	0.0593
75.5	0.05	3.775	0.0707	75.5	0.05	3.775	0.0710
71.5	0.1	7.15	0.2535	71.5	0.1	7.15	0.2545
75.6	0.1	7.56	0.2834	75.6	0.1	7.56	0.2846
78.51	0.1	7.851	0.3056	78.51	0.1	7.851	0.3069
75.4	0.1	7.54	0.2819	75.4	0.1	7.54	0.2831
70.5	0.1	7.05	0.2464	70.5	0.1	7.05	0.2475
74.5	0.1	7.45	0.2752	74.5	0.1	7.45	0.2764
70.6	0.05	3.53	0.0618	70.6	0.05	3.53	0.0620
43.5	0.05	2.175	0.0235	43.5	0.05	2.175	0.0236
38.5	0.05	1.925	0.0184	38.5	0.05	1.925	0.0185
50	0.05	2.5	0.0310	50	0.05	2.5	0.0311
53.2	0.05	2.66	0.0351	53.2	0.05	2.66	0.0352
57.8	0.05	2.89	0.0414	57.8	0.05	2.89	0.0416
56.9	0.05	2.845	0.0401	56.9	0.05	2.845	0.0403
64.4	0.1	6.44	0.2056	64.4	0.1	6.44	0.2065
36	0.1	3.6	0.0643	36	0.1	3.6	0.0645
53.2	0.1	5.32	0.1403	53.2	0.1	5.32	0.1409
Total	**3.55**	**201.7038**	**7.3771**	**Total**	**3.55**	**200.8358**	**7.2852**

		Relative HRI =	**57.37 %**			**Relative HRI =**	**56.66%**
After +5% increase in x2				**After +10% increase in x2**			
Avg. rating of risk factors (Xi)	**% composition of risks**	**Weightage of risk factors = X_i*% composition**	**HRI score**	**Avg. rating of risk factors (X_i)**	**% composition of risks**	**Weightage of risk factors = X_i***	**HRI score**
44.4	0.2	8.88	0.3860	44.4	0.2	8.88	0.3852
30	0.2	6	0.1762	30	0.2	6	0.1758
86.8	0.2	17.36	1.4751	86.8	0.2	17.36	1.4721
41.65	0.2	8.33	0.3396	41.65	0.2	8.33	0.3389
62.07	0.1	6.207	0.1886	62.07	0.1	6.207	0.1882
40.8	0.1	4.08	0.0815	40.8	0.1	4.08	0.0813
49	0.1	4.9	0.1175	49	0.1	4.9	0.1173
86.898	0.1	8.6898	0.3696	91.036	0.1	9.1036	0.4048
39.9	0.1	3.99	0.0779	39.9	0.1	3.99	0.0778
43.8	0.1	4.38	0.0939	43.8	0.1	4.38	0.0937
38.5	0.15	5.775	0.1632	38.5	0.15	5.775	0.1629
64	0.15	9.6	0.4511	64	0.15	9.6	0.4502
76.4	0.15	11.46	0.6428	76.4	0.15	11.46	0.6415
30.7	0.15	4.605	0.1038	30.7	0.15	4.605	0.1036
70.8	0.15	10.62	0.5520	70.8	0.15	10.62	0.5509
74.4	0.05	3.72	0.0677	74.4	0.05	3.72	0.0676
69	0.05	3.45	0.0583	69	0.05	3.45	0.0581
75.5	0.05	3.775	0.0698	75.5	0.05	3.775	0.0696
71.5	0.1	7.15	0.2502	71.5	0.1	7.15	0.2497
75.6	0.1	7.56	0.2797	75.6	0.1	7.56	0.2792
78.51	0.1	7.851	0.3017	78.51	0.1	7.851	0.3011
75.4	0.1	7.54	0.2783	75.4	0.1	7.54	0.2777
70.5	0.1	7.05	0.2433	70.5	0.1	7.05	0.2428
74.5	0.1	7.45	0.2717	74.5	0.1	7.45	0.2711
70.6	0.05	3.53	0.0610	70.6	0.05	3.53	0.0609
43.5	0.05	2.175	0.0232	43.5	0.05	2.175	0.0231
38.5	0.05	1.925	0.0181	38.5	0.05	1.925	0.0181
50	0.05	2.5	0.0306	50	0.05	2.5	0.0305
53.2	0.05	2.66	0.0346	53.2	0.05	2.66	0.0346
57.8	0.05	2.89	0.0409	57.8	0.05	2.89	0.0408
56.9	0.05	2.845	0.0396	56.9	0.05	2.845	0.0395
64.4	0.1	6.44	0.2030	64.4	0.1	6.44	0.2026
36	0.1	3.6	0.0634	36	0.1	3.6	0.0633
53.2	0.1	5.32	0.1385	53.2	0.1	5.32	0.1382
Total	**3.55**	**204.3078**	**7.6924**	**Total**	**3.55**	**204.7216**	**7.7128**

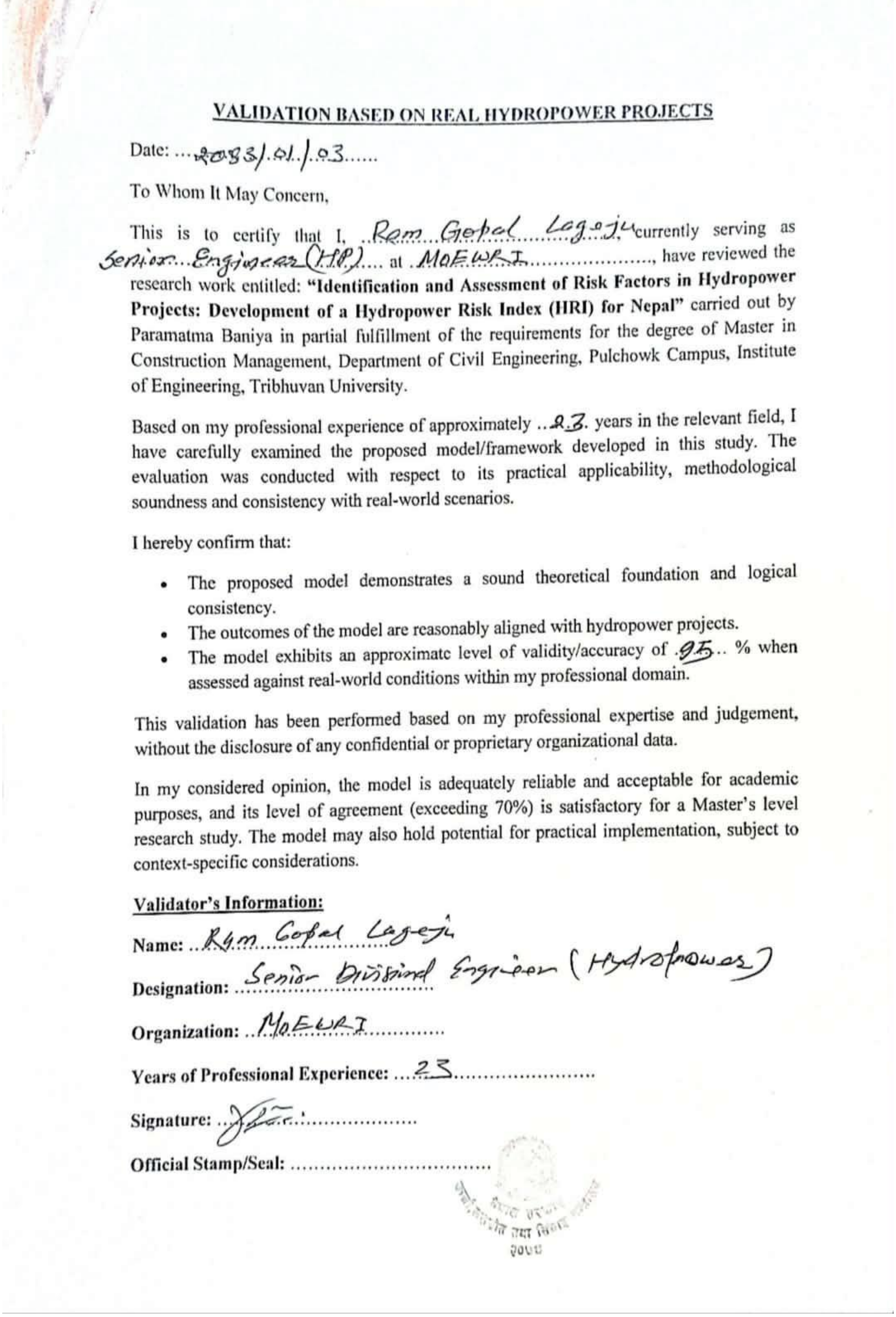
		Relative HRI =	**59.83 %**			**Relative HRI =**	**59.99%**
After +15% increase in x2				**After +20% increase in x2**			
Avg. rating of risk factors (Xi)	**% composition of risks**	**Weightage of risk factors = X_i*% composition**	**HRI score**	**Avg. rating of risk factors (X_i)**	**% composition of risks**	**Weightage of risk factors = X_i***	**HRI score**
44.4	0.2	8.88	0.3844	44.4	0.2	8.88	0.3836
30	0.2	6	0.1755	30	0.2	6	0.1751
86.8	0.2	17.36	1.4691	86.8	0.2	17.36	1.4662
41.65	0.2	8.33	0.3383	41.65	0.2	8.33	0.3376
62.07	0.1	6.207	0.1878	62.07	0.1	6.207	0.1874
40.8	0.1	4.08	0.0811	40.8	0.1	4.08	0.0810
49	0.1	4.9	0.1170	49	0.1	4.9	0.1168
95.174	0.1	9.5174	0.4416	99.312	0.1	9.9312	0.4798
39.9	0.1	3.99	0.0776	39.9	0.1	3.99	0.0775
43.8	0.1	4.38	0.0935	43.8	0.1	4.38	0.0933
38.5	0.15	5.775	0.1626	38.5	0.15	5.775	0.1623
64	0.15	9.6	0.4493	64	0.15	9.6	0.4484
76.4	0.15	11.46	0.6402	76.4	0.15	11.46	0.6389
30.7	0.15	4.605	0.1034	30.7	0.15	4.605	0.1032
70.8	0.15	10.62	0.5498	70.8	0.15	10.62	0.5487
74.4	0.05	3.72	0.0675	74.4	0.05	3.72	0.0673
69	0.05	3.45	0.0580	69	0.05	3.45	0.0579
75.5	0.05	3.775	0.0695	75.5	0.05	3.775	0.0693
71.5	0.1	7.15	0.2492	71.5	0.1	7.15	0.2487
75.6	0.1	7.56	0.2786	75.6	0.1	7.56	0.2781
78.51	0.1	7.851	0.3005	78.51	0.1	7.851	0.2999
75.4	0.1	7.54	0.2771	75.4	0.1	7.54	0.2766
70.5	0.1	7.05	0.2423	70.5	0.1	7.05	0.2418
74.5	0.1	7.45	0.2706	74.5	0.1	7.45	0.2700
70.6	0.05	3.53	0.0607	70.6	0.05	3.53	0.0606
43.5	0.05	2.175	0.0231	43.5	0.05	2.175	0.0230
38.5	0.05	1.925	0.0181	38.5	0.05	1.925	0.0180
50	0.05	2.5	0.0305	50	0.05	2.5	0.0304
53.2	0.05	2.66	0.0345	53.2	0.05	2.66	0.0344
57.8	0.05	2.89	0.0407	57.8	0.05	2.89	0.0406
56.9	0.05	2.845	0.0395	56.9	0.05	2.845	0.0394
64.4	0.1	6.44	0.2022	64.4	0.1	6.44	0.2018
36	0.1	3.6	0.0632	36	0.1	3.6	0.0631
53.2	0.1	5.32	0.1380	53.2	0.1	5.32	0.1377
Total	**3.55**	**205.1354**	**7.7348**	**Total**	**3.55**	**205.5492**	**7.7584**

		Relative HRI =	**60.16 %**			**Relative HRI =**	**60.34%**
After -5% increase in x2				**After -10% increase in x2**			
Avg. rating of risk factors (Xi)	**% composition of risks**	**Weightage of risk factors = X_i*% composition**	**HRI score**	**Avg. rating of risk factors (X_i)**	**% composition of risks**	**Weightage of risk factors = X_i***	**HRI score**
44.4	0.2	8.88	0.3875	44.4	0.2	8.88	0.3883
30	0.2	6	0.1769	30	0.2	6	0.1773
86.8	0.2	17.36	1.4811	86.8	0.2	17.36	1.4841
41.65	0.2	8.33	0.3410	41.65	0.2	8.33	0.3417
62.07	0.1	6.207	0.1893	62.07	0.1	6.207	0.1897
40.8	0.1	4.08	0.0818	40.8	0.1	4.08	0.0820
49	0.1	4.9	0.1180	49	0.1	4.9	0.1182
78.622	0.1	7.8622	0.3038	74.484	0.1	7.4484	0.2732
39.9	0.1	3.99	0.0782	39.9	0.1	3.99	0.0784
43.8	0.1	4.38	0.0943	43.8	0.1	4.38	0.0945
38.5	0.15	5.775	0.1639	38.5	0.15	5.775	0.1642
64	0.15	9.6	0.4529	64	0.15	9.6	0.4538
76.4	0.15	11.46	0.6454	76.4	0.15	11.46	0.6467
30.7	0.15	4.605	0.1042	30.7	0.15	4.605	0.1044
70.8	0.15	10.62	0.5543	70.8	0.15	10.62	0.5554
74.4	0.05	3.72	0.0680	74.4	0.05	3.72	0.0681
69	0.05	3.45	0.0585	69	0.05	3.45	0.0586
75.5	0.05	3.775	0.0700	75.5	0.05	3.775	0.0702
71.5	0.1	7.15	0.2512	71.5	0.1	7.15	0.2518
75.6	0.1	7.56	0.2809	75.6	0.1	7.56	0.2815
78.51	0.1	7.851	0.3029	78.51	0.1	7.851	0.3035
75.4	0.1	7.54	0.2794	75.4	0.1	7.54	0.2800
70.5	0.1	7.05	0.2443	70.5	0.1	7.05	0.2448
74.5	0.1	7.45	0.2728	74.5	0.1	7.45	0.2733
70.6	0.05	3.53	0.0612	70.6	0.05	3.53	0.0614
43.5	0.05	2.175	0.0232	43.5	0.05	2.175	0.0233
38.5	0.05	1.925	0.0182	38.5	0.05	1.925	0.0182
50	0.05	2.5	0.0307	50	0.05	2.5	0.0308
53.2	0.05	2.66	0.0348	53.2	0.05	2.66	0.0348
57.8	0.05	2.89	0.0410	57.8	0.05	2.89	0.0411
56.9	0.05	2.845	0.0398	56.9	0.05	2.845	0.0399
64.4	0.1	6.44	0.2038	64.4	0.1	6.44	0.2042
36	0.1	3.6	0.0637	36	0.1	3.6	0.0638
53.2	0.1	5.32	0.1391	53.2	0.1	5.32	0.1394
Total	**3.55**	**203.4802**	**7.6563**	**Total**	**3.55**	**203.0664**	**7.6407**

		Relative HRI =	59.55 %			Relative HRI =	59.43%
After -15% increase in x2				**After -20% increase in x2**			
Avg. rating of risk factors (Xi)	**% composition of risks**	**Weightage of risk factors = X_i*% composition**	**HRI score**	**Avg. rating of risk factors (X_i)**	**% composition of risks**	**Weightage of risk factors = X_i***	**HRI score**
44.4	0.2	8.88	0.3891	44.4	0.2	8.88	0.3899
30	0.2	6	0.1776	30	0.2	6	0.1780
86.8	0.2	17.36	1.4871	86.8	0.2	17.36	1.4902
41.65	0.2	8.33	0.3424	41.65	0.2	8.33	0.3431
62.07	0.1	6.207	0.1901	62.07	0.1	6.207	0.1905
40.8	0.1	4.08	0.0821	40.8	0.1	4.08	0.0823
49	0.1	4.9	0.1185	49	0.1	4.9	0.1187
70.346	0.1	7.0346	0.2442	66.208	0.1	6.6208	0.2167
39.9	0.1	3.99	0.0786	39.9	0.1	3.99	0.0787
43.8	0.1	4.38	0.0947	43.8	0.1	4.38	0.0949
38.5	0.15	5.775	0.1646	38.5	0.15	5.775	0.1649
64	0.15	9.6	0.4548	64	0.15	9.6	0.4557
76.4	0.15	11.46	0.6481	76.4	0.15	11.46	0.6494
30.7	0.15	4.605	0.1046	30.7	0.15	4.605	0.1049
70.8	0.15	10.62	0.5565	70.8	0.15	10.62	0.5577
74.4	0.05	3.72	0.0683	74.4	0.05	3.72	0.0684
69	0.05	3.45	0.0587	69	0.05	3.45	0.0589
75.5	0.05	3.775	0.0703	75.5	0.05	3.775	0.0705
71.5	0.1	7.15	0.2523	71.5	0.1	7.15	0.2528
75.6	0.1	7.56	0.2820	75.6	0.1	7.56	0.2826
78.51	0.1	7.851	0.3042	78.51	0.1	7.851	0.3048
75.4	0.1	7.54	0.2805	75.4	0.1	7.54	0.2811
70.5	0.1	7.05	0.2453	70.5	0.1	7.05	0.2458
74.5	0.1	7.45	0.2739	74.5	0.1	7.45	0.2744
70.6	0.05	3.53	0.0615	70.6	0.05	3.53	0.0616
43.5	0.05	2.175	0.0233	43.5	0.05	2.175	0.0234
38.5	0.05	1.925	0.0183	38.5	0.05	1.925	0.0183
50	0.05	2.5	0.0308	50	0.05	2.5	0.0309
53.2	0.05	2.66	0.0349	53.2	0.05	2.66	0.0350
57.8	0.05	2.89	0.0412	57.8	0.05	2.89	0.0413
56.9	0.05	2.845	0.0399	56.9	0.05	2.845	0.0400
64.4	0.1	6.44	0.2047	64.4	0.1	6.44	0.2051
36	0.1	3.6	0.0640	36	0.1	3.6	0.0641
53.2	0.1	5.32	0.1397	53.2	0.1	5.32	0.1399
Total	**3.55**	**202.6526**	**7.6268**	**Total**	**3.55**	**202.2388**	**7.6144**

		Relative HRI =	**59.32 %**			**Relative HRI =**	**59.22%**

APPENDIX 5: Validation Based on Real Hydropower Projects



VALIDATION BASED ON REAL HYDROPOWER PROJECTS

Date: ...2083/01/03......

To Whom It May Concern,

This is to certify that I, ..Ram Gopal Lageju currently serving as Senior Engineer (HP).... at .MoEWRI......................, have reviewed the research work entitled: **"Identification and Assessment of Risk Factors in Hydropower Projects: Development of a Hydropower Risk Index (HRI) for Nepal"** carried out by Paramatma Baniya in partial fulfillment of the requirements for the degree of Master in Construction Management, Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University.

Based on my professional experience of approximately ..23. years in the relevant field, I have carefully examined the proposed model/framework developed in this study. The evaluation was conducted with respect to its practical applicability, methodological soundness and consistency with real-world scenarios.

I hereby confirm that:

- The proposed model demonstrates a sound theoretical foundation and logical consistency.
- The outcomes of the model are reasonably aligned with hydropower projects.
- The model exhibits an approximate level of validity/accuracy of .95.. % when assessed against real-world conditions within my professional domain.

This validation has been performed based on my professional expertise and judgement, without the disclosure of any confidential or proprietary organizational data.

In my considered opinion, the model is adequately reliable and acceptable for academic purposes, and its level of agreement (exceeding 70%) is satisfactory for a Master's level research study. The model may also hold potential for practical implementation, subject to context-specific considerations.

Validator's Information:

Name: ..Ram Gopal Lageju

Designation: Senior Divisional Engineer (Hydropower)

Organization: ..MoEWRI............

Years of Professional Experience: ...23.......................

Signature: ....

Official Stamp/Seal: ....

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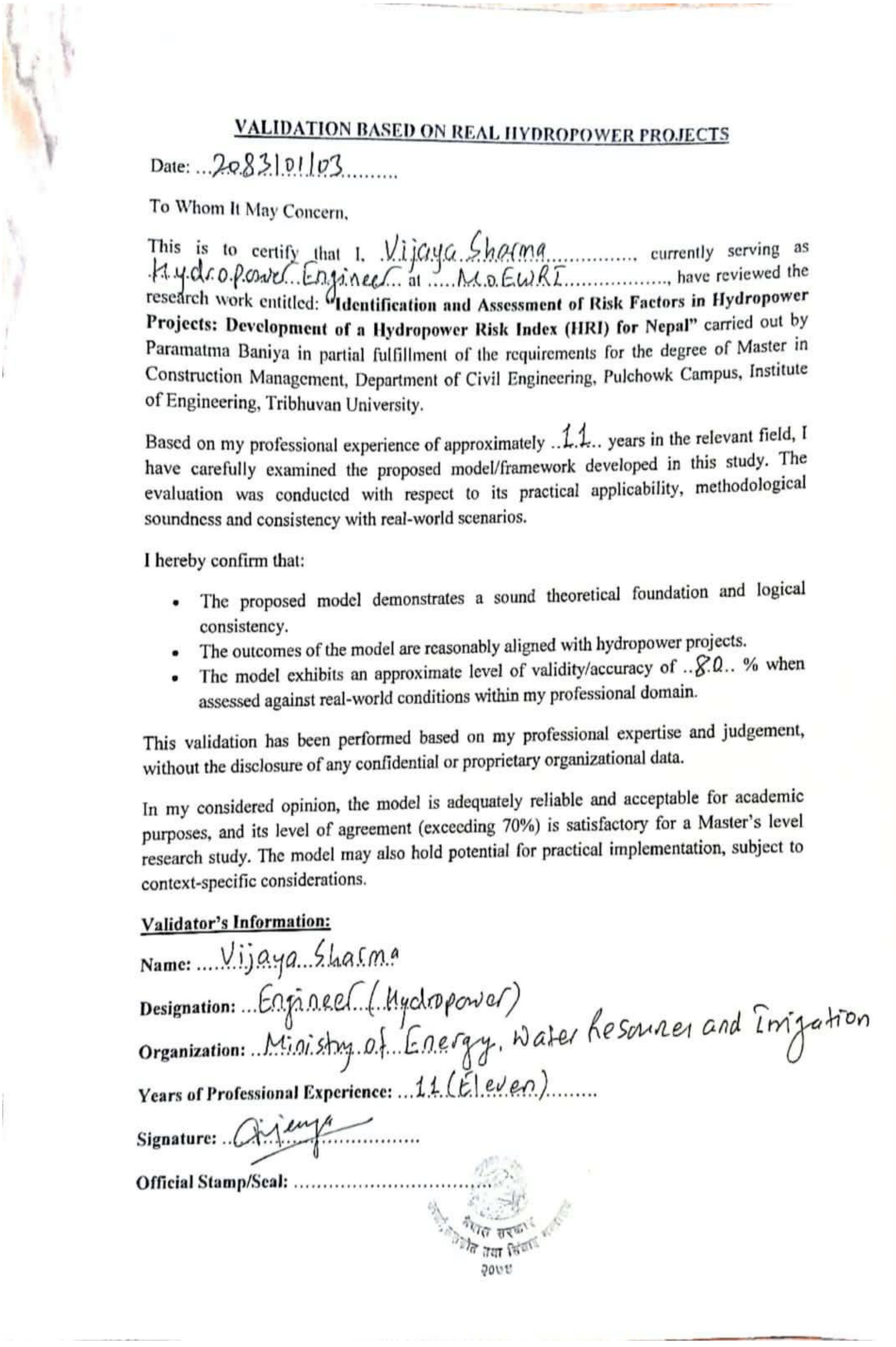

VALIDATION BASED ON REAL HYDROPOWER PROJECTS

Date: ...2083/01/03.........

To Whom It May Concern,

This is to certify that I, Vijaya Sharma............... currently serving as Hydropower Engineer at .....MoEWRI.................., have reviewed the research work entitled: **"Identification and Assessment of Risk Factors in Hydropower Projects: Development of a Hydropower Risk Index (HRI) for Nepal"** carried out by Paramatma Baniya in partial fulfillment of the requirements for the degree of Master in Construction Management, Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University.

Based on my professional experience of approximately ..11.. years in the relevant field, I have carefully examined the proposed model/framework developed in this study. The evaluation was conducted with respect to its practical applicability, methodological soundness and consistency with real-world scenarios.

I hereby confirm that:

- The proposed model demonstrates a sound theoretical foundation and logical consistency.
- The outcomes of the model are reasonably aligned with hydropower projects.
- The model exhibits an approximate level of validity/accuracy of ..80.. % when assessed against real-world conditions within my professional domain.

This validation has been performed based on my professional expertise and judgement, without the disclosure of any confidential or proprietary organizational data.

In my considered opinion, the model is adequately reliable and acceptable for academic purposes, and its level of agreement (exceeding 70%) is satisfactory for a Master's level research study. The model may also hold potential for practical implementation, subject to context-specific considerations.

Validator's Information:

Name: ....Vijaya Sharma

Designation: ...Engineer (Hydropower)

Organization: ...Ministry of Energy, Water Resources and Irrigation

Years of Professional Experience: ...11 (Eleven)........

Signature: ..Vijaya..................

Official Stamp/Seal: ....

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APPENDIX 6: Factors Identification & Expert Validation of Risk Factors for Hydropower Projects

Table A6. 1 Expert Validation of Risk Factors for Hydropower Projects

S.No.	Risk factors	Questions	Remarks	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Validation
1	Incomplete geological & hydrological investigation	To what extent are geological and hydrological investigations conducted thoroughly before finalizing the design?	Abd El-Karim et al., 2017; Agarwal & Kansal, 2020	✓	x	✓	✓	✓	x	4/6 (Valid)
2	Poor dam design or tunnel alignment	How appropriate and accurate are the dam design and tunnel alignment decisions based on field conditions?	Abd El-Karim et al., 2017; Agarwal & Kansal, 2020	✓	✓	✓	x	✓	✓	5/6 (Valid)
3	Frequent design revisions during construction	To what extent do design revisions during construction contribute to delays and cost overruns?	Abd El-Karim et al., 2017; Chileshe & Yirenkyi-Fianko, 2012; Rauzana, 2016	x	✓	x	✓	x	x	2/6 (Invalid)
4	Difficult topography & terrain	To what degree do difficult topography and terrain impact design feasibility?	Chileshe & Boadua Yirenkyi-Fianko, 2012; Chaudhary, 2024	✓	x	✓	✓	x	✓	4/6 (Valid)
5	Lack of adaptability to remote site conditions	How effectively is the design adapted to remote and logistically challenging site conditions?	Chileshe & Boadua Yirenkyi-Fianko, 2012; Maharjan, 2025	✓	✓	✓	✓	✓	✓	6/6 (Valid)
6	Poor coordination between contractors, consultants & local authorities	To what extent are communication and coordination mechanisms clearly established among contractors, consultants, and local authorities?	Sudirman & Hardjomuljadi, 2011; Tripathi et al., 2017	✓	✓	x	✓	✓	✓	5/6 (Valid)
7	Inexperience in managing hydropower complexity	How experienced is the project management team in handling the technical complexity of hydropower projects?	Gunasekaran et al., 2014; Sudirman & Hardjomuljadi, 2011	x	✓	✓	x	✓	✓	4/6 (Valid)
8	Ineffective stakeholder communication	How well are project objectives and progress communicated to all stakeholders including local communities?	Tripathi et al., 2017; Shaktawat & Vadhera, 2021	✓	✓	✓	✓	✓	✓	6/6 (Valid)
9	Ineffective inter-agency and cross-border coordination	How effectively are inter-agency and cross-border coordination issues managed in trans-basin or regional hydropower projects?	Tang et al., 2013; MRC Guidelines, n.d.; Shaktawat & Vadhera, 2021	✓	x	x	✓	x	x	2/6 (Invalid)
10	Remote access leads to supply delays	To what extent does the remoteness of the hydropower project site cause delays in the delivery of materials and equipment?	Maharjan, 2025; Shaktawat & Vadhera, 2021	✓	x	✓	x	✓	✓	4/6 (Valid)
11	Skilled hydropower workforce shortages	How adequate is the availability of skilled hydropower workforce to meet project demands?	Maharjan, 2025; Chaudhary, 2024	✓	✓	✓	✓	x	✓	5/6 (Valid)
12	Inefficient procurement and management of spare parts and consumables	How efficiently are spare parts and consumables procured and managed for continuous construction progress?	Sudirman & Hardjomuljadi, 2011; Yucesan & Kahraman, 2019; Oksuz & Brlek, 2023	x	x	x	✓	x	x	1/6 (Invalid)
13	Equipment inaccessibility or unsuitability for terrain	How suitable and accessible is the construction equipment for the challenging terrain of the project site?	Shaktawat & Vadhera, 2021; Tripathi et al., 2017	✓	x	✓	x	✓	✓	4/6 (Valid)
14	Reliability and Creditworthiness of the Offtaker (Buyer)	To what extent is the power purchaser (offtaker) financially reliable and consistent in fulfilling payment obligations?	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024	x	✓	✓	✓	✓	x	4/6 (Valid)

S.No.	Risk factors	Questions	Remarks	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Validation
15	Inadequate allocation and utilization of contingency budgets	How effectively are contingency budgets allocated and utilized to address unforeseen financial challenges?	Agarwal & Kansal, 2020; Li et al., 2023; Abd El-Karim et al., 2017	✓	✗	✗	✗	✗	✗	1/6 (Invalid)
16	Grid Availability and Dispatch Risk	To what extent is the national or regional grid consistently available to dispatch the generated power from the hydropower plant?	Tang et al., 2013; Bhatt & Joshi, 2024	✓	✓	✓	✓	✓	✓	6/6 (Valid)
17	Delay in financial closure	To what extent do delays in achieving financial closure affect the overall project timeline?	Agarwal & Kansal, 2020; Tang et al., 2013	✗	✓	✓	✓	✓	✓	5/6 (Valid)
18	Difficulty in securing private sector investment	How attractive is Nepal's hydropower sector to private investors in terms of risk and return?	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024	✓	✗	✓	✗	✓	✓	4/6 (Valid)
19	Underestimation of tunnel or powerhouse costs	To what extent do actual tunnel or powerhouse construction costs exceed initial estimates due to site-specific challenges?	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024	✓	✓	✓	✓	✓	✓	6/6 (Valid)
20	Cost escalation due to imported machinery	To what extent has the project faced cost escalation due to the dependency on imported machinery?	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024	✗	✓	✓	✓	✗	✓	4/6 (Valid)
21	Foreign exchange risks for loan repayments	How significant is the impact of foreign exchange rate fluctuations on the repayment of foreign loans for the project?	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024	✓	✓	✓	✓	✗	✓	5/6 (Valid)
22	Inflation during long project durations	To what extent does inflation during long project durations affect the overall project cost and budgeting?	Agarwal & Kansal, 2020; Bhatt & Joshi, 2024	✓	✓	✓	✓	✓	✓	6/6 (Valid)
23	Political instability and frequent leadership changes	To what extent do political instability and changes in leadership influence project continuity and decision-making?	Chaudhary, 2024; Bhatt & Joshi, 2024; Shaktawat & Vadhera, 2021	✓	✗	✗	✗	✓	✗	2/6 (Invalid)
24	Unstable regulatory framework	To what extent do frequent changes in laws or regulations impact the planning and execution of hydropower projects?	Rezakhani, n.d.; Rauzana, 2016	✓	✓	✗	✓	✓	✗	4/6 (Valid)
25	Bureaucratic delays in permits	How often are project activities delayed due to procedural or administrative delays in obtaining government approvals and permits?	Rezakhani, n.d.; Rauzana, 2016	✗	✓	✓	✗	✓	✓	4/6 (Valid)
26	Local-level opposition or interference	To what extent does opposition or interference from local communities or political groups affect project implementation and progress?	Shaktawat & Vadhera, 2021; Rezakhani, n.d.	✓	✓	✓	✓	✓	✓	6/6 (Valid)
27	High environmental sensitivity of project area (protected zones, rivers)	To what extent is the project location within highly environmentally sensitive zones like protected areas or rivers?	Chaudhary, 2024; Sudirman & Hardjomuljadi, 2011	✓	✓	✓	✗	✓	✓	5/6 (Valid)
28	Landslides, glacial lake outburst floods (GLOFs), monsoon floods	How likely are landslides, GLOFs, or monsoon floods to impact the project site and timeline?	Chaudhary, 2024; Tripathi et al., 2017	✓	✗	✓	✗	✓	✓	4/6 (Valid)

S.No.	Risk factors	Questions	Remarks	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Validation
29	Delays due to EIAs and compliance	To what extent do delays in Environmental Impact Assessment (EIA) approval and compliance affect project implementation?	Sudirman & Hardjomuljadi, 2011; Tripathi et al., 2017	✓	✓	✓	✓	✓	x	5/6 (Valid)
30	Poor implementation of environmental mitigation measures	How effectively are mitigation measures implemented to minimize adverse impacts identified in the Environmental Impact Assessment (EIA)?	MRC Guidelines, n.d.; Shaktawat & Vadhera, 2021; Tang et al., 2013	x	x	x	✓	x	x	1/6 (Invalid)
31	Land acquisition disputes	To what extent do land acquisition processes in your project face disputes with local landowners or communities?	Abd El-Karim et al., 2017; Chileshe & Boadua Yirenkyi-Fianko, 2012	x	✓	x	✓	✓	✓	4/6 (Valid)
32	Inadequate compensation or resettlement	How adequately are affected individuals compensated or resettled during land acquisition and project implementation?	Abd El-Karim et al., 2017; Goji Tipili et al., n.d.	✓	✓	✓	✓	✓	✓	6/6 (Valid)
33	Cultural/indigenous rights violations	To what extent are cultural sensitivities and indigenous rights considered and respected in project planning and execution?	Goji Tipili et al., n.d.; Chileshe & Boadua Yirenkyi-Fianko, 2012	✓	x	✓	✓	x	✓	4/6 (Valid)
34	Protest and local strikes	How frequently does your project experience protests, strikes, or disruptions from local communities due to social or environmental concerns?	Goji Tipili et al., n.d.; Tripathi et al., 2017	✓	✓	x	✓	✓	✓	5/6 (Valid)
35	Ambiguous risk-sharing clauses in BOOT contracts	To what extent are the risk-sharing responsibilities clearly defined and understood among parties in BOOT contracts in your hydropower project?	Tripathi et al., 2017; Gunasekaran et al., 2014	✓	✓	✓	✓	✓	✓	6/6 (Valid)
36	Claims and disputes over design responsibility	How often do claims or disputes arise due to unclear allocation of design responsibility among stakeholders?	Gunasekaran et al., 2014; Tripathi et al., 2017	x	✓	✓	✓	x	✓	4/6 (Valid)
37	International arbitration complexities	To what extent do international arbitration procedures pose challenges in resolving contractual disputes in your hydropower project?	Tripathi et al., 2017; Gunasekaran et al., 2014	✓	x	✓	✓	✓	✓	5/6 (Valid)
38	Delays in grid connection	To what extent do delays in grid connection affect the timely operation of hydropower projects?	Sudirman & Hardjomuljadi, 2011; Tang et al., 2013	✓	✓	✓	✓	✓	✓	6/6 (Valid)
39	Generation below expected capacity due to poor hydrological prediction	How accurately are hydrological predictions made to estimate generation capacity before project commissioning?	Sudirman & Hardjomuljadi, 2011; Tang et al., 2013	✓	✓	x	✓	✓	x	4/6 (Valid)
40	O&M challenges post-construction	How effectively are operation and maintenance (O&M) challenges managed after project construction?	Shaktawat & Vadhera, 2021; Sudirman & Hardjomuljadi, 2011	✓	x	✓	✓	✓	✓	5/6 (Valid)
41	Inadequate emergency preparedness and disaster response planning	To what extent are emergency preparedness and disaster response plans established and tested for operational safety?	Pescaroli et al., 2020; Oksuz & Brlek, 2023; Sudirman & Hardjomuljadi, 2011	x	✓	✓	x	x	x	2/6 (Invalid)

Table A6. 2 List of Hydropower Experts Engaged for KII Validation

S. No.	Expert name	Contact No.	Working sector
1	Parshu Ram Bogati	9841475204	Manager Hydropower, HIDCL
2	Kabindra Gautam	9842127114	Simbuwa Remit Hydro Ltd.
3	Basu Dev Bhandari	9841525765	Chief Manager Hydropower, HIDCL
4	Ram Gopal Lageju	9841372927	S.D.E., Hydropower, MoEWRI
5	Anup Dhungana	9840051075	S.D.E., Hydropower, MoEWRI
6	Vijaya Sharma	9849074773	Hydropower Engineer, MoEWRI

APPENDIX 7: Acceptance of Paper for 18th IoE Graduate Conference

4/28/26, 6:09 PM Gmail - [IOEGC18] Editor Decision

Paramatma Baniya <paramatmabaniya16@gmail.com>

[IOEGC18] Editor Decision

1 message

Dr. Pradeep Shrestha <ioegc17@gmail.com> 28 April 2026 at 09:13

To: PARAMATMA BANIYA <paramatmabaniya16@gmail.com>, Mahendra Raj Dhital <mrdhital@ioe.edu.np>, Nagendra Bahadur Amatya <nbamatya@ioe.edu.np>

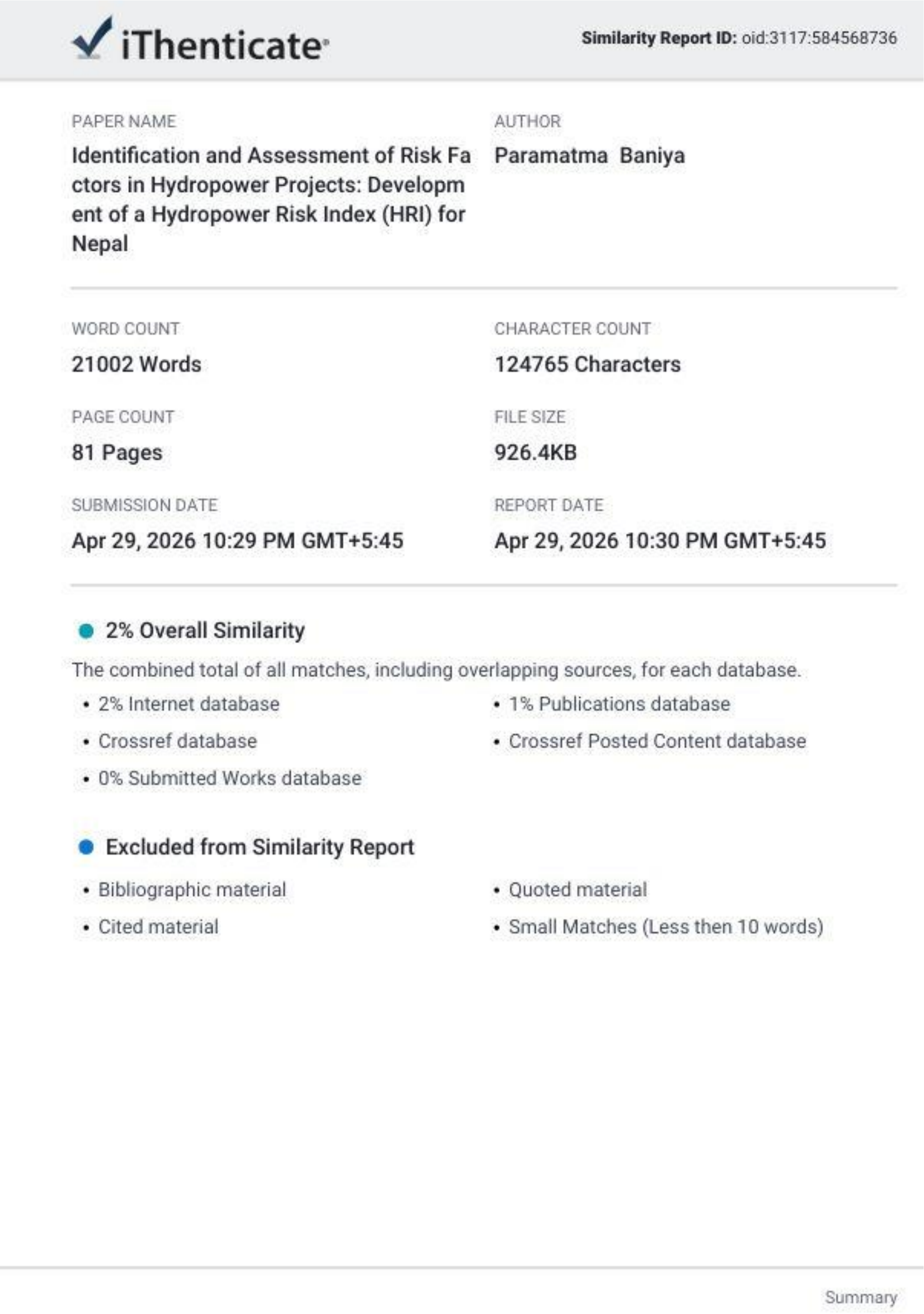
PARAMATMA BANIYA, Mahendra Raj Dhital, Nagendra Bahadur Amatya:

We have reached a decision regarding your submission to 18th IOE Graduate Conference, "Identification and Assessment of Risk Factors in Hydropower Projects: Development of a Hydropower Risk Index (HRI)".

Our decision is to: Accept Submission

With Warm Regards,
IOEGC-18 Editorial Team

APPENDIX 8: Originality Report



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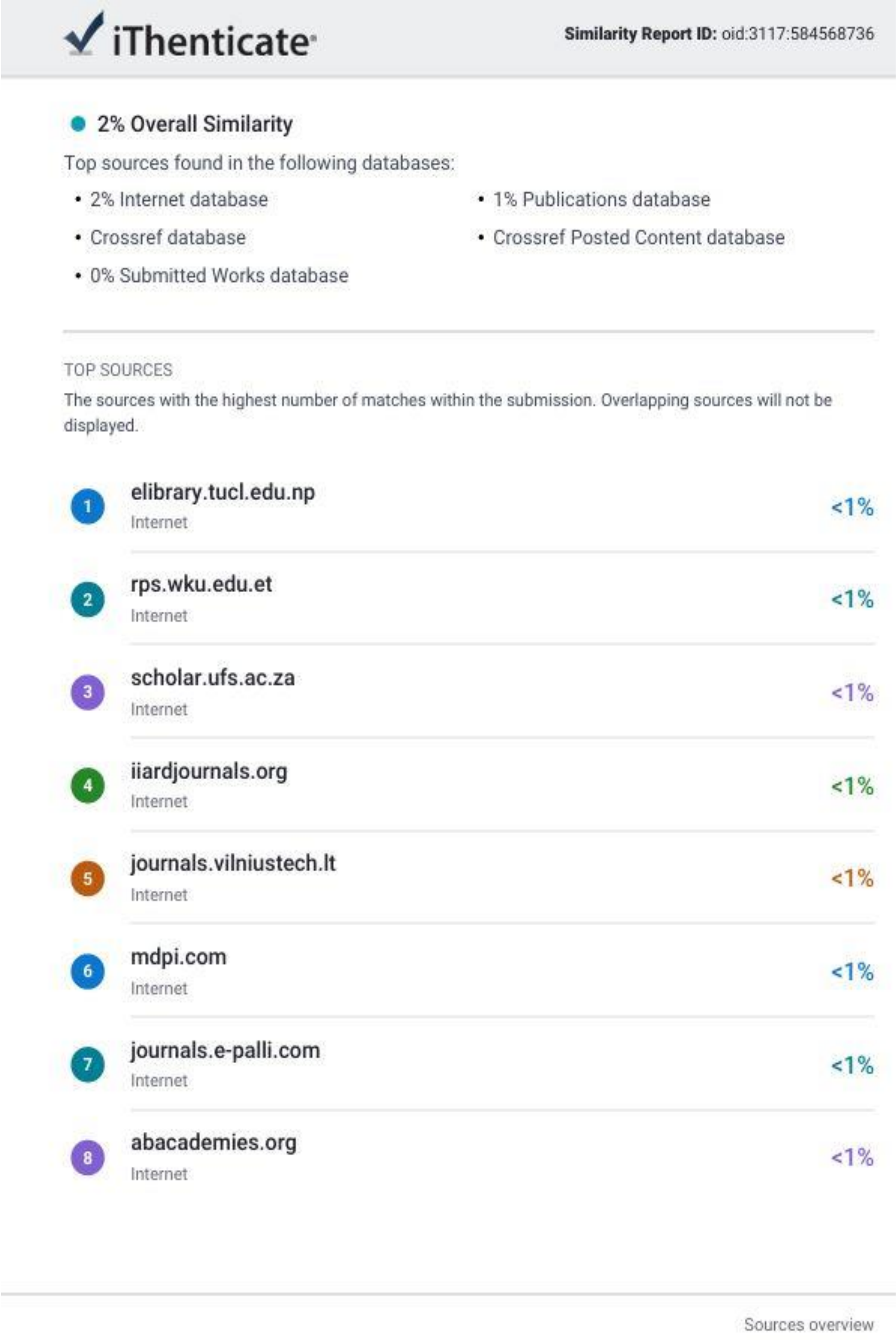

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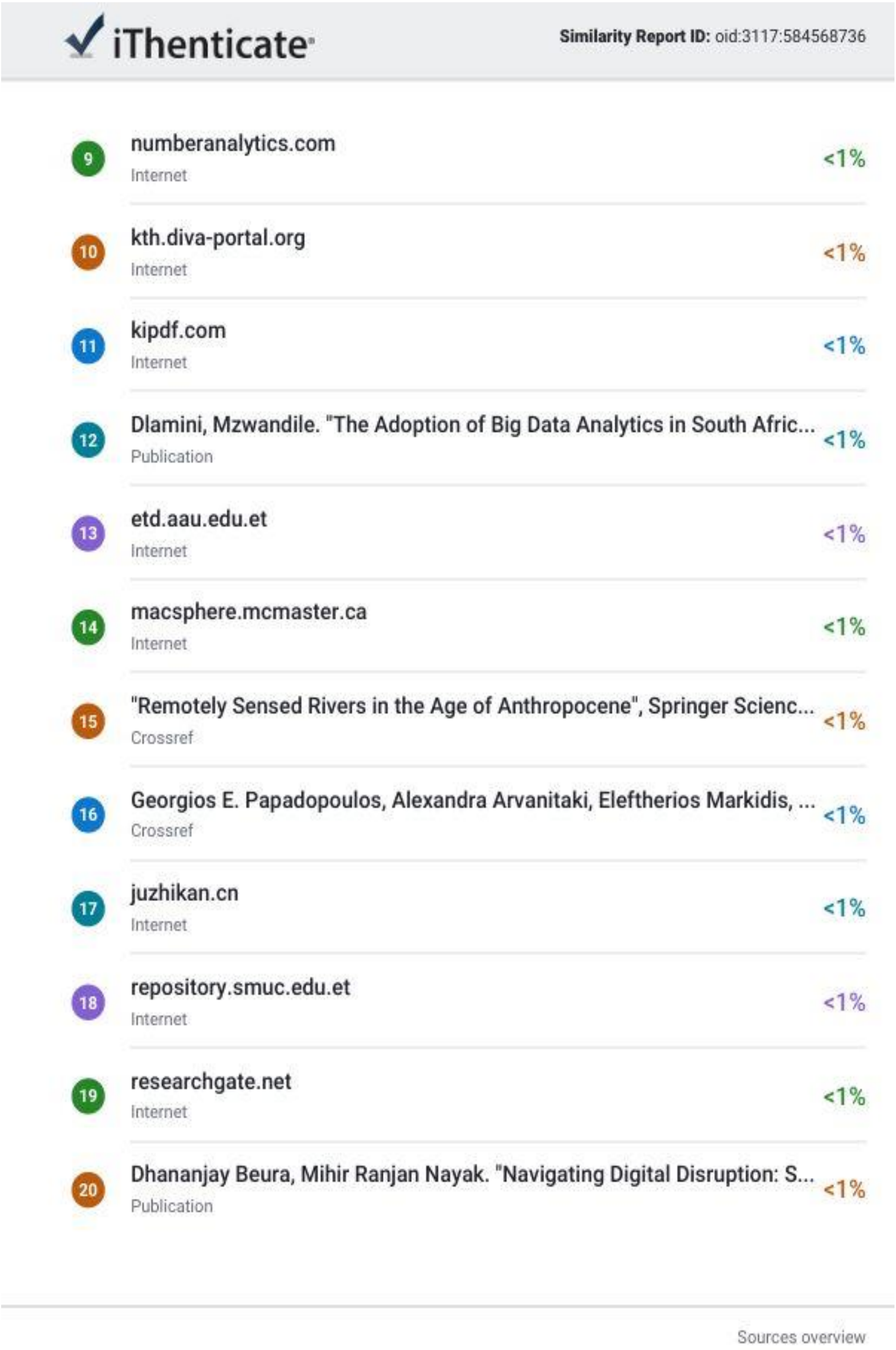

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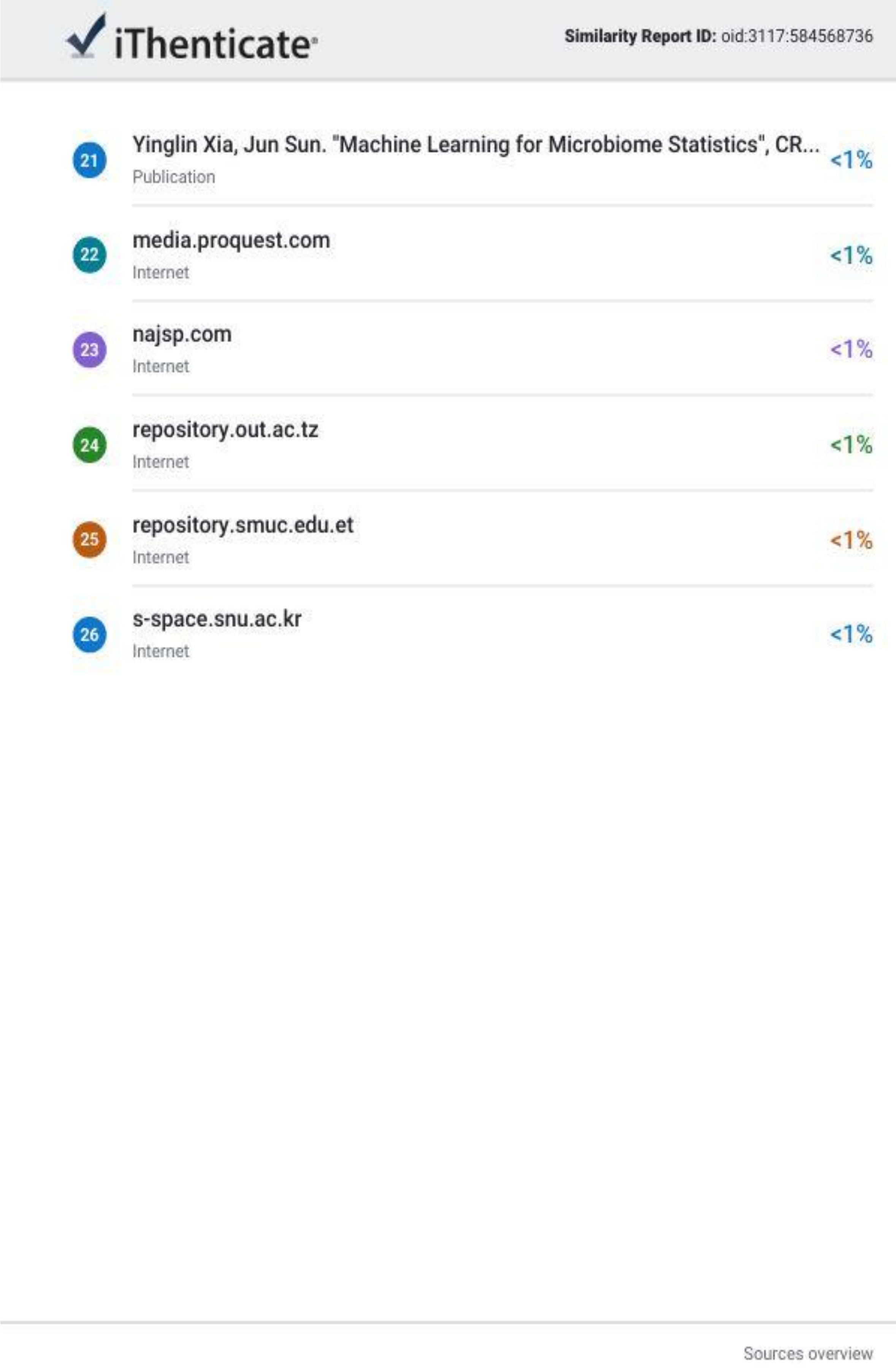

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