Identification, Assessment and Management of Critical Risks in Hydroelectric Projects

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Abstract: Hydroelectric projects are among the most important sources of renewable energy generation and play a vital role in the sustainable development of a country. However, these projects are characterized by significant uncertainties and complexities arising from geological, environmental, financial, technical, socio-political and managerial factors. Effective risk management is therefore essential to ensure successful project delivery within the desired time, cost, quality, safety and environmental performance objectives. The present study focuses on the identification, assessment, ranking and management of critical risks associated with hydroelectric projects in the Indian context. A comprehensive literature review was carried out to identify potential risk factors, followed by a structured questionnaire survey involving professionals such as project managers, construction managers, engineers, consultants and contractors engaged in hydroelectric projects. The collected responses were analyzed using Risk Probability Index (PI), Severity Index (SI), Risk Potential Value (RPV) and Risk Assessment Matrix techniques to evaluate the significance of individual risks. The analysis revealed that land acquisition issues, rehabilitation and resettlement challenges, unforeseen geological conditions at tunneling locations, flooding and extreme precipitation events, labour strikes, adverse geological formations, difficult site accessibility, project time constraints, natural disasters, and financial resource shortages are among the most critical risks affecting hydroelectric project performance. These risks have a significant impact on project schedule, cost, quality, and overall project success. Based on the findings, appropriate risk mitigation and management strategies have been proposed to reduce the likelihood and consequences of identified risks. The outcomes of this study can assist project owners, consultants, contractors, policymakers and stakeholders in developing proactive risk management frameworks for improving the performance and sustainability of future hydroelectric projects.

Keywords: Hydroelectric Projects, Risk Assessment, Risk Management, Risk Potential Value, Risk Mitigation, Construction Management, Project Performance, Sustainable Development.

1. Introduction

1.1 General

Energy is one of the fundamental drivers of economic growth, industrial development, and social progress. With the rapid increase in population, urbanization, and industrial activities, the demand for electricity has grown significantly across the world. In response to concerns regarding climate change, environmental degradation, and depletion of fossil fuel reserves, nations are increasingly shifting towards renewable energy sources. Among the available renewable energy options, hydropower remains one of the most mature, reliable, and cost-effective technologies for large-scale electricity generation. Hydroelectric power contributes substantially to global renewable energy production and plays a crucial role in achieving sustainable development goals. Compared to thermal power plants, hydropower projects produce electricity with minimal greenhouse gas emissions and provide additional benefits such as flood control, irrigation support, water supply management, and regional economic development. Owing to these advantages, many developing countries, including India, continue to invest heavily in hydropower infrastructure. India possesses significant hydropower potential due to its vast river network, favorable topography, and diverse climatic conditions. According to various national energy assessments, the country has considerable untapped hydropower resources, particularly in the Himalayan and northeastern regions. Hydroelectric projects have therefore become an important component of India's strategy for ensuring energy security and promoting sustainable economic growth. However, despite their strategic importance, many hydropower projects in India experience substantial delays, cost overruns, contractual disputes, environmental challenges, and operational uncertainties. Hydroelectric projects are inherently complex because of their large scale, long construction periods, substantial capital investment requirements, and dependence on site-specific geological and environmental conditions. Unlike conventional construction projects, hydropower developments involve multiple interconnected components such as dams, reservoirs, diversion tunnels, spillways, powerhouses, transmission facilities, and associated infrastructure. The successful completion of these facilities requires effective coordination among various stakeholders including government agencies, project owners, contractors, consultants, local communities, environmental authorities, and financial institutions. The complexity of hydroelectric projects introduces numerous uncertainties throughout the project lifecycle.

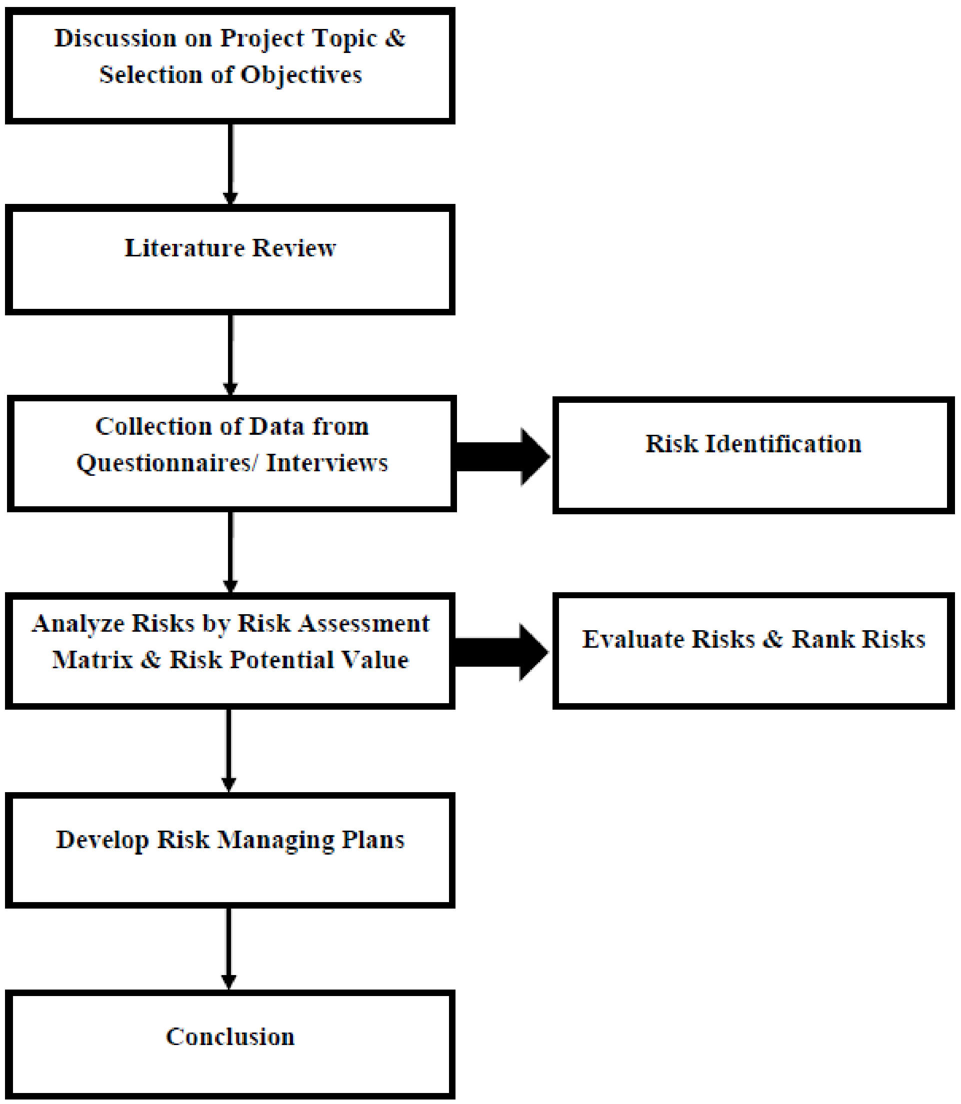
1.2 Need of The Study

Hydroelectric projects are essential for renewable energy generation and sustainable development. However, these projects are often affected by various risks such as land acquisition problems, geological uncertainties, environmental challenges, financial constraints, and management issues. These risks frequently lead to project delays, cost overruns, and reduced performance. Many hydroelectric projects in India have faced significant difficulties due to inadequate risk identification and management during the planning and construction stages. Therefore, it is necessary to identify, assess, and prioritize critical risks so that appropriate mitigation measures can be implemented. This study aims to support project stakeholders in improving project planning, minimizing uncertainties, and enhancing the successful execution of hydroelectric projects.

1.3 Objective

The specific objectives of the study are as follows:

1. To identify the major risk factors involved in the planning, design, construction, and execution of hydroelectric projects.
2. To classify identified risks into different categories such as financial, construction, environmental, socio-political, management, physical, legal, and technical risks.
3. To evaluate the probability of occurrence and severity of impact of individual risk factors using a structured questionnaire survey.
4. To assess and rank critical risks using Risk Probability Index (PI), Severity Index (SI), Risk Potential Value (RPV), and Risk Assessment Matrix techniques.
5. To determine the most significant risks affecting project cost, schedule, quality, safety, and overall project performance.
6. To develop suitable risk mitigation and management strategies for minimizing the adverse effects of identified risks.
7. To provide a practical risk management framework that can support decision-making and improve the successful delivery of future hydroelectric projects.
8. To contribute towards the sustainable development and effective implementation of hydropower projects through systematic risk assessment and management practices.



1.1 Research Methodology

2 Literature Review

Several researchers have highlighted the importance of risk management in construction and infrastructure projects.

Al-Bahar and Crandall (1990) developed a Construction Risk Management System (CRMS) for systematic identification and management of construction risks.

Akintoye and MacLeod (1997) emphasized that risk significantly influences project cost, time, and quality performance and advocated structured risk analysis approaches.

Kucukali (2011) applied fuzzy logic techniques for hydropower risk assessment and identified geological and environmental risks as dominant contributors to project uncertainty.

Patel and Singhal (2015) reported that land acquisition, resettlement, legal approvals, and project execution decisions are major causes of delays in hydropower projects.

Previous studies indicate that although risk management practices are increasingly adopted in construction industries, hydroelectric projects continue to face substantial challenges due to their complexity and site-specific characteristics.

3. Research Methodology

In this paper, at the outset, general focus has been made on the general concepts of project risk management. Literature provides the theoretical context about the project. The various risk factors involved in the construction of hydroelectric power projects are determined from literature review, telephonic conversations and from the past record of construction of hydroelectric projects and a questionnaire is designed and different risk factors were put into eight categories, with 12 risks related to financial problems, 21 related to construction, 6 related to environment, 11 related to socio-political risks, 11 related to management, 5 related to physical risks, 4 related to legal risks and 6 are technical risks. The questionnaire consisted of three sections. Section I consists information about the company profile and section II contains information about respondent. Section III carried a total of 76 risks associated with construction of hydroelectric projects and asked respondents to review and indicate the probability of these risks using five point scale ranging from 1 to 5 (rarely, sometimes, frequently, very frequently, mostly) and the level of impact on each project objective that would result in as very low, low, medium, high, and very high (1 to 5).To achieve the objectives of this paper, questionnaire was deemed to be the most helpful tool for collecting information. The general methodology of this study relies largely on the survey questionnaires, which were distributed through electronic mailing to 36 respondents (mainly people who work in hydroelectric projects who enjoy a leading role in planning and construction management, e.g., project managers, general managers, civil engineers) from government and construction companies in the defined area of study. Usable questionnaire were returned by 20 respondents consisting of 2 contract officers, 2 senior managers, 3 project managers, 4 construction managers, 9 engineers. Subsequently results from interviews and questionnaires are presented. Discussion is done on the results from the interview and then risks identified are analyzed and compared to theoretical framework. Finally the final recommendations are drawn up in the conclusion section.

A. Risk Management in Hydroelectric Projects

Risk management is an ongoing and iterative process which should be conducted throughout the life cycle of a hydroelectric project. Risk management is a systematic way of identifying, analyzing and responding to risks to achieve the objectives of hydroelectric project in terms of time, cost, quality, safety and environmental sustainability. Risk management is probably the most difficult phase of project management. Managing risks in construction of hydroelectric projects has been recognized as a very important process in order to achieve project objectives. Risk management in hydroelectric projects includes: risk identification, risk analysis, risk response planning, risk monitoring and control. Risk identification is the first and most important step in risk management process as it identifies the source and type of risks. Risk identification develops the basis for next steps of risk management process. A large number of tools and techniques exist for risk identification such as: Brain storming, Risk checklists, Interviews, Questionnaires, Past experience, Delphi techniques, Visit location, Historical data from similar projects, Study specialist literature (Kansal and Sharma, 2012). Identification of risks in hydroelectric projects relies mostly on questionnaire survey and past experience that should be used in upcoming projects.

B. Risk Analysis and Assessment

After the risks are identified they must be individually assessed as to their potential probability and consequence (Borge, 2001).Qualitative analysis of data for risk assessment can be done by risk assessment matrix and risk potential value method. Risk potential value method (A x B) is used to rank the risk exposure by assessing the subjective probability and impact of each risk event.

Risk Probability = Σ an/N×A×100

(Where a= constant expressing the weight assigned to each responses from 1 to 5, n= probability of each response, N= total number of responses, A= highest weight (i.e. 5 in this case)

Risk Impact = Σ an/N×A×100

(Where a= constant expressing the weight assigned to each responses from 1 to 5, n=impact of each response, N= total number of responses, A=highest weight (i.e. 5 in this case)

Risk Potential = Risk Probability (A) x Risk Impact (B)

Then risk exposures can be ranked in descending order in order to select the major risk events requiring further analysis. A simple probability and impact matrix for each risk event is developed. Risk exposure can be categorized into four main categories as low, medium, high and critical. Quantitative method of risk assessment is done for potentially high exposure risks, which are ranked after the risk qualitative analysis method. The choice of risk quantification techniques will depend upon the nature of risk under consideration. There are various techniques used for quantitative risk analysis such as: Decision tree and decision network analysis, Sensitivity analysis, expected monetary value (EMV), Scenario analysis, Probabilistic analysis (MCS) and PERT network analysis technique.

4. Result and Discussions

During construction of hydroelectric project, risks can result from many circumstances. Based on the data analyzed earlier, a total of 7 sources of risks in hydroelectric projects are identified and analyzed. Once the risk factors in hydroelectric project are determined, risk probability and risk impact can be calculated as shown in Table 1.The risk assessment matrix illustrates a risk rating for individual risk factors in the identified risk categories. The risk assessment matrix shows the combination of probability and impact that in turn yield a risk priority (shown by red, orange, green and blue color). Risk with high probability and high impact such as C20 (Unpredicted geological structure at tunneling sites), SP2 (Land acquisition problems), SP3(Resettlement & rehabilitation), C4(Adverse geological conditions) ,C6 (Laborstrikes), C17 (Accessconditions), E1(Natural disasters), E4(Flooding), F10 (Owner financial capacity), F11(Paucity of funds), M8(Time constraint), M9(Project delay) are required further analysis. According to risk potential value method (A x B) major risk factors can be identified among the factors which lie in the critical region in the risk assessment matrix.

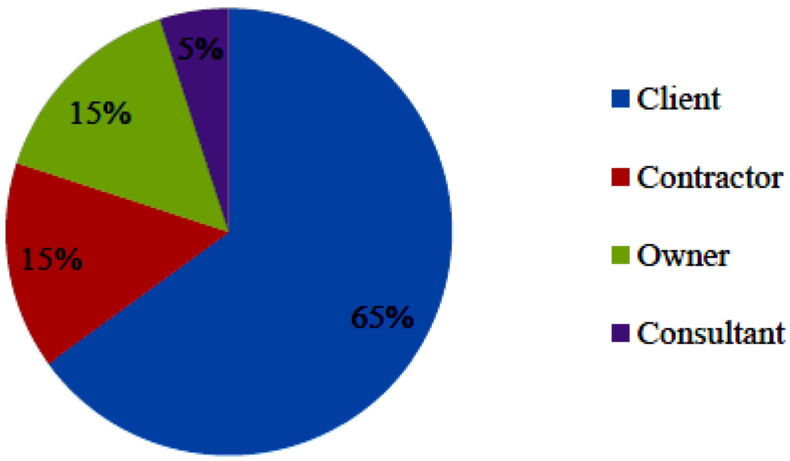


Figure 4.1 Response Rate for Different Categories for the Questionnaire

Table I-Risk Categories

I.D	Risk Factors	Risk Probability (A)	Risk Impact (B)	Risk Potential (AxB)
	Financial Risks			
F1	Loss due to fluctuation of interest rate	0.41	0.38	0.16
F2	Low credibility of shareholder and lender	0.56	0.61	0.34
F3	Change in bank formalities and lenders	0.34	0.41	0.14
F4	Loss due to rise in fuel prices	0.4	0.42	0.17
F5	Increased material cost	0.65	0.78	0.51
F6	Insurances risk	0.55	0.61	0.34
F7	Improper estimation	0.62	0.8	0.50
F8	Payment delays	0.53	0.69	0.37
F9	Invoices delay	0.46	0.54	0.25
F10	Owner financial capacity	0.62	0.81	0.50
F11	Paucity of funds	0.65	0.82	0.53
F12	Tax rate	0.5	0.59	0.30
	Construction Risks			
C1	Labor availability	0.61	0.73	0.45
C2	Drop in labor productivity	0.58	0.72	0.42
C3	Differing site conditions	0.63	0.67	0.42
C4	Adverse geological conditions	0.77	0.81	0.62
C5	Faulty construction work at site	0.61	0.73	0.45
C6	Labor strikes	0.78	0.87	0.68
C7	Labor disputes	0.66	0.72	0.48
C8	Equipment quality	0.62	0.7	0.43

C9	Equipment maintenance	0.56	0.61	0.34
C10	Material delivery	0.66	0.76	0.50
C11	Material shortage	0.64	0.75	0.48
C12	Material procurement	0.54	0.67	0.36
C13	New technology	0.54	0.66	0.36
C14	Nominated vendors	0.53	0.55	0.29
C15	Delay in permits and licenses	0.54	0.64	0.35
C16	Site location (rural/urban)	0.7	0.72	0.50
C17	Access conditions	0.76	0.82	0.62
C18	Seepage problem from dam	0.62	0.69	0.43
C19	Blasting work	0.68	0.71	0.48
C20	Unpredicted geological structure at tunneling	0.83	0.88	0.73
C21	Design changes	0.68	0.72	0.49
	Environmental Risks			
E1	Natural disasters	0.66	0.84	0.55
E2	Earthquake	0.55	0.77	0.42
E3	Landslides	0.74	0.7	0.52
E4	Precipitation/Flooding	0.77	0.9	0.69
E5	Unpredicted weather conditions	0.6	0.69	0.41
E6	Adverse environmental conditions	0.58	0.66	0.38
	Socio-political Risks			
SP1	Changes in laws and regulations	0.5	0.64	0.32
SP2	Land acquisition problems	0.85	0.95	0.81
SP3	Resettlement & rehabilitation	0.84	0.91	0.76
SP4	Litigations	0.62	0.73	0.45
SP5	Pollution and safety rules	0.5	0.55	0.28
SP6	Bribery/Corruption	0.45	0.52	0.23
SP7	Language/Cultural barrier	0.47	0.48	0.23
SP8	Law and order	0.44	0.59	0.26
SP9	War and civil disorder	0.35	0.6	0.21
SP10	Social acceptance	0.54	0.65	0.35
SP11	Requirements for permits and their approval	0.54	0.69	0.37
	Management Risks			
M1	Change in top management	0.54	0.68	0.37
M2	No past experience in similar project	0.59	0.74	0.44
M3	Short tender time	0.47	0.63	0.30

M4	Internal management problem	0.57	0.69	0.39
M5	Improper project feasibility study	0.53	0.76	0.40
M6	Poor relation and disputes with partner	0.58	0.74	0.43
M7	Teamwork	0.56	0.73	0.41
M8	Time constraint	0.69	0.81	0.56
M9	Project delay	0.65	0.81	0.53
M10	Quality control process	0.63	0.71	0.45
M11	Type of contract	0.65	0.72	0.47
	Physical Risks			
P1	Damage to structure	0.53	0.73	0.39
P2	Damage to equipment	0.5	0.66	0.33
P3	Labor accidents	0.61	0.66	0.40
P4	Equipment breakdown	0.57	0.71	0.40
P5	Material theft & damage	0.58	0.57	0.33
	Legal Risks			
L1	Breach of contract by project partner	0.43	0.53	0.23
L2	Lack of enforcement of legal judgment	0.46	0.53	0.24
L3	Improper verification of contract document	0.49	0.59	0.29
L4	Uncertainty and unfairness of court justice	0.39	0.51	0.20
	Technical Risks			
T1	In complete design	0.52	0.7	0.36
T2	Inadequate specification	0.55	0.69	0.38
T3	Inadequate site investigation	0.6	0.72	0.43
T4	Change in scope	0.59	0.71	0.42
T5	Construction procedures	0.61	0.71	0.43
T6	Insufficient resource availability	0.61	0.77	0.47

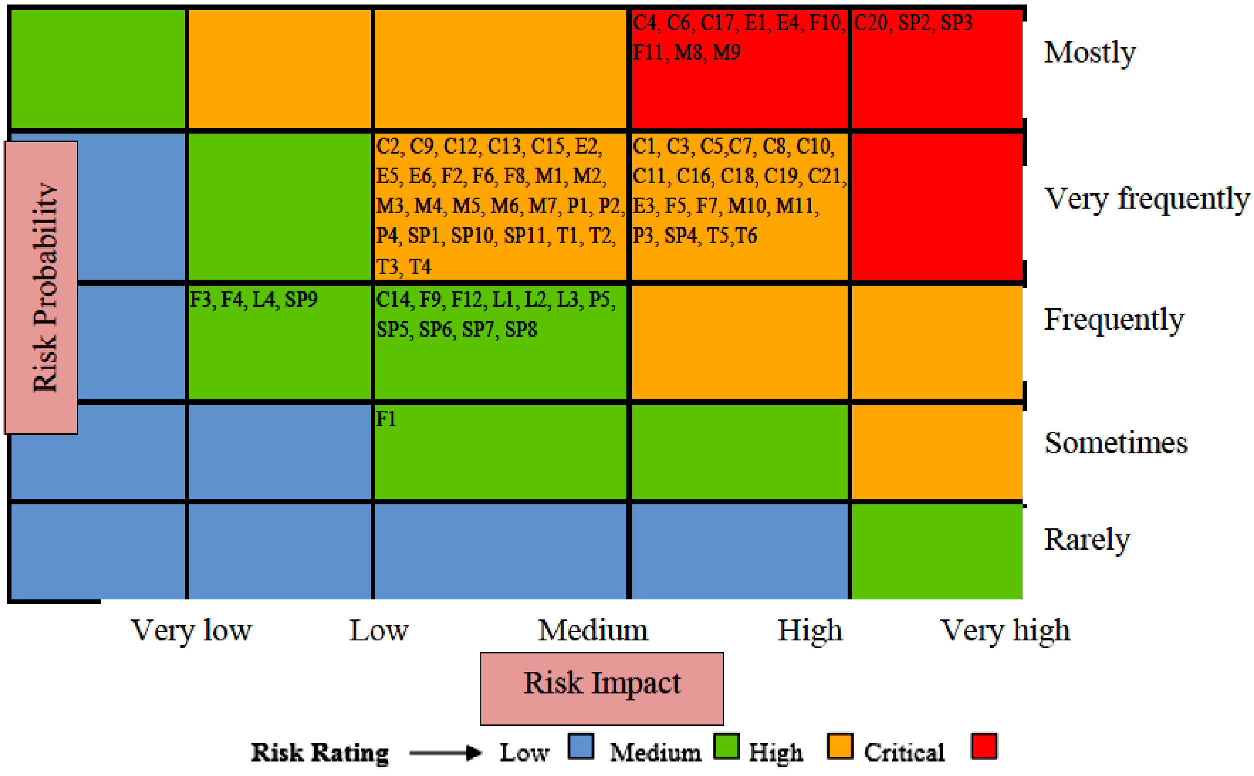


Figure 4.2 Risk Assessment Matrix

Table II-Ranking of Risk Factors According to Risk Potential Value Method

Risk Factors	Rank
Land acquisition problems	1
Resettlement & rehabilitation	2
Unpredicted geological structure at tunneling sites	3
Precipitation/Flooding	4
Labor strikes	5
Adverse geological conditions	6
Access conditions	7
Time constraint	8
Natural disasters	9
Paucity of funds	10

5 Conclusions

The present study focused on the identification, assessment, ranking, and management of critical risks associated with hydroelectric projects. Through an extensive literature review and a structured questionnaire survey involving professionals engaged in hydropower projects, various financial, construction, environmental, socio-political, management, legal, physical, and technical risks were identified and analyzed. Risk Probability Index (PI), Severity Index (SI), Risk Potential Value (RPV), and Risk Assessment Matrix techniques were employed to evaluate the significance of individual risk factors. The results indicate that environmental, construction, and socio-political risks are the most influential risk categories affecting the successful execution of hydroelectric projects. Among the identified risks, land acquisition problems, rehabilitation and resettlement issues, unforeseen geological conditions at tunneling locations, precipitation and flooding, labour strikes, adverse geological formations, difficult site accessibility, project time constraints, natural disasters, and shortage of financial resources were found to be the most critical risk factors based on their Risk Potential Values. The study further reveals that inadequate risk management practices remain a major challenge in many hydroelectric projects. Risk management is often implemented in an informal manner, and only a limited number of organizations adopt systematic procedures for risk identification, assessment, monitoring, and mitigation. Consequently, many projects experience schedule delays, cost overruns, and reduced project performance. The findings emphasize that the adoption of a structured risk management framework during the planning and construction stages can significantly reduce project uncertainties and improve decision-making. Early identification of critical risks, continuous monitoring, stakeholder participation, detailed site investigations, and proactive mitigation measures are essential for enhancing project success.

References

1. Al-Bahar, J. F. and Crandall, K. C. (1990). "Systematic risk management approach for construction projects." *Journal of Construction Engineering and Management*, ASCE, 533-546.
2. Kangari, R. (1995). "Risk management perceptions and trends of U.S. Construction." *Journal of Construction Engineering and Management, ASCE*, 422-429.
3. Akintoye, A. S. and MacLeod, M. J. (1997). "Risk analysis and management in construction." *International Journal of Project Management*, Vol. 15, 31-38.
4. Hillson, D. A. (1997). "Towards a risk maturity model." *The International Journal of Project & Business Risk Management*, Vol. 1, 35-45.
5. Minato, T. and Ashley, D. B. (1998). "Data-driven analysis of "Corporate Risk" using historical cost-control data." *Journal of Construction Engineering and Management, ASCE*, 42-47.
6. Mak, S. and Picken, D. (2000). "Using risk analysis to determine construction project contingencies." *Journal of Construction Engineering and Management, ASCE*, 130-136.
7. Barber, R. B. (2005). "Understanding internally generated risks in projects." *International Journal of Project Management*, 584-590.
8. Imbeah, W. and Guikema, S. (2009). "Managing construction projects using the advanced programmatic risk analysis and management model." *Journal of Construction Engineering and Management*, ASCE, 772-781.
9. Zou, P. X. W., Chen, Y. and Chan, T. (2010). "Understanding and improving your risk management capability: assessment model for construction organizations." *Journal of Construction Engineering and Management*, ASCE, 854-863.

10. Kucukali, S. (2011). "risk assessment of river type hydropower plants by using fuzzy logic approach." *World Renewable Energy Congress- Sweden*, 8-13.
11. Kansal, R. K. and Sharma, M. (2012). "Risk assessment methods and application in the construction projects." *International Journal of Modern Engineering Research (IJMER)*, Vol. 2, 1081-1085.
12. Mahendra, P. A., Pitroda, J. R. and Bhavsar, J. J. (2013). "A study of risk management techniques for construction projects in developing countries."