CAUSAL ANALYSIS AND PRIORITIZATION OF ENVIRONMENTAL RISK FACTORS IN HIGH-RISE BUILDING PROJECTS USING A FUZZY DEMATEL APPROACH IN ADDIS ABABA

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A THESIS SUBMITTED TO THE SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE OF ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN CONSTRUCTION AND MANAGEMENT

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Causal Analysis and Prioritization of Environmental Risk Factors in High-Rise Building Projects Using a Fuzzy DEMATEL Approach in Addis Ababa

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DECLARATION

I, **Elias Ketsela**, declare that this thesis entitled **“Causal Analysis and Prioritization of Environmental Risk Factors in High-Rise Building Projects Using a Fuzzy DEMATEL Approach in Addis Ababa”** is my own work and has not been submitted to any university for similar purpose. The references used in this thesis are duly recognized by proper citations.

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I, Meseret Getnet [PhD], the major advisor/supervisor of this thesis, hereby certify that I have closely advised/supervised the student while writing this thesis and read the thesis/dissertation entitled **"Causal Analysis and Prioritization of Environmental Risk Factors in High-Rise Building Projects Using a Fuzzy DEMATEL Approach in Addis Ababa"** prepared under my guidance by Elias Ketsela. Therefore, I recommend the submission of the thesis to the department for further review and evaluation.

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APPROVAL PAGE THESIS

I hereby certify that the recommendation and suggestion given by the thesis review the committee are appropriately incorporated into the final thesis entitled **"Causal Analysis and Prioritization of Environmental Risk Factors in High-Rise Building Projects Using a Fuzzy DEMATEL Approach in Addis Ababa"** by Elias Ketsela.

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ABSTRACT

High-rise building construction projects in rapidly urbanizing centers like Addis Ababa are inherently susceptible to a multitude of environmental risk factors (ERFs), which can adversely impact project objectives and broader environmental sustainability. Current risk management practices often inadequately address the complex interdependencies among these ERFs. This study aimed to conduct a comprehensive causal analysis and prioritization of ERFs affecting high-rise building construction projects in Addis Ababa using the Fuzzy DEMATEL methodology, and to leverage these insights for developing a targeted strategic management framework. Employing a mixed-methods, sequential explanatory design, data were collected through a literature review and two phases of expert consultations. An initial list of ERFs was validated by experts, resulting in 23 key factors. Subsequently, a panel of 13 experts provided pairwise comparison judgments on these ERFs, which were analyzed using Fuzzy DEMATEL. The analysis identified 'Weak enforcement of existing environmental regulations' (ERF22; D-R = 0.22) and 'Adverse Geological Conditions' (ERF9; D-R = 0.71), and 'Earthquake/Seismic Activity' (ERF7; D-R = 0.52) as key dispatcher ERFs. Highly prominent ERFs included 'Land Pollution' (ERF15; D+R = 10.77) and ERF22 (D+R = 10.70), while 'Public Health and Safety Risks' (ERF20; D-R = -0.72) was the most significant receiver. These findings informed a strategic management framework focusing on proactive measures for dispatchers and robust mitigation for receivers, validated by five experts. This research concludes that a systemic, data-driven approach is crucial for effective ERF management. Recommendations include strengthening regulatory enforcement, enhancing pre-construction assessments for dispatcher risks, and implementing integrated strategies for prominent receiver ERFs. The developed framework offers a practical tool for stakeholders to improve environmental performance in Addis Ababa's high-rise construction sector.

Keywords: *Addis Ababa, Causal Analysis, Environmental Risk Factors, Fuzzy DEMATEL, High-Rise Construction, Risk Prioritization, Strategic Management*

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LIST OF ACRONYMS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
C&D	Construction and Demolition (waste)
COPRAS	Complex Proportional Assessment
COPRAS-G	Grey COPRAS
D+R	Prominence (Sum of dispatched and received influence in DEMATEL)
D-R	Relation (Net causal effect; Difference between dispatched and received influence in DEMATEL)
DEMATEL	Decision-Making Trial and Evaluation Laboratory
EMV	Expected Monetary Value
ERF(s)	Environmental Risk Factor(s)
FA	Factor Analysis
FAHP	Fuzzy Analytic Hierarchy Process
FDEMATEL	Fuzzy Decision-Making Trial and Evaluation Laboratory
FDRE	Federal Democratic Republic of Ethiopia
FGDEMATEL	Fuzzy Grey Decision-Making Trial and Evaluation Laboratory
FMEA	Failure Mode and Effects Analysis
IRM	Influence Relation Map
KPIs	Key Performance Indicators
M.Eng	Master of Engineering
MA	Master of Arts
MABAC	Multi-Attributive Border Approximation Area Comparison
MBA	Master of Business Administration
MCDM	Multi-Criteria Decision-Making

MCS	Monte Carlo Simulation
MSc	Master of Science
PEng	Professional Engineer
PESTLE	Political, Economic, Social, Technological, Legal, Environmental
PhD	Doctor of Philosophy
PLS-SEM	Partial Least Squares Structural Equation Modeling
RBS	Risk Breakdown Structures
RII	Relative Importance Index
SEM	Structural Equation Modeling
TFN(s)	Triangular Fuzzy Number(s)
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The construction industry plays a pivotal role in the economic development of any country (Amarasekara et al., 2018). However, construction projects are inherently complex and vulnerable to various risks throughout their life cycle (Abu Qalbin et al., 2023). These risks can negatively impact crucial project objectives, such as cost, time, quality, health and safety, and environmental performance (Adedokun et al., 2023).

Among the diverse categories of risks, environmental factors present significant challenges in construction (Alfadil et al., 2022). These factors encompass issues related to the natural and built environment, including pollution, waste management, resource consumption, and compliance with environmental regulations, which can arise during project execution and operation (Adedokun and Egbelakin, 2024). Effective environmental protection is increasingly recognized as important for achieving sustainable development, particularly in construction (Tessema et al., 2022). Sustainable building construction, while offering numerous benefits, is often considered riskier than traditional methods, necessitating specific risk assessment (Alawneh et al., 2024). Inadequate control of sustainability risk factors can lead to poor project performance and difficult decisions (Erdenekhuu et al., 2022). Environmental impacts of construction activities, such as air, water, and land pollution, water consumption, and solid waste, are crucial concerns that need to be assessed from a sustainable perspective (Erdenekhuu et al., 2022).

The challenges posed by construction risks, including environmental ones, are particularly pronounced in developing countries (Bahamid et al., 2019). Factors such as weak economies, unstable policies, and socio-cultural specificities can exacerbate the impact of external risks (Al Kassem et al., 2020). In some developing regions, risk management practices may be deficient due to a lack of knowledge or budget (Mitikie et al., 2017). Ethiopia, for instance, faces significant challenges in its construction sector, including issues leading to cost and time overruns (Tessema et al., 2022). Building construction projects in Addis Ababa have experienced considerable time overruns due to various problems encountered during different project phases (Mitikie et al., 2017). Studies in Ethiopia have also highlighted that risk management practices may not be fully developed (Kivrak and Udan, O2023). While studies have identified key risk factors in Ethiopian construction, including those related to economic conditions (like inflation), design issues, and management deficiencies, environmental factors have sometimes been ranked lower in perceived importance compared to other regions, although their impact on sustainability is acknowledged (Tessema et al., 2022). The concept of sustainable construction itself is noted as relatively new in Ethiopia, with a low degree of adoption partly due to associated risks (Tessema et al., 2022).

Given the complexity, distinctiveness, and fragmentation inherent in construction projects, coupled with the significant impacts risks can have on project outcomes and sustainability, effective risk management is crucial (Adedokun and Egbelakin, 2024). This process typically involves identifying, assessing, and developing response strategies for potential risks (Amarasekara et al., 2018). Various methods and techniques are employed for risk assessment and prioritization in construction, such as Structural Equation Modeling (SEM), PLS-SEM, PESTLE analysis, Relative Importance Index (RII), Analytic Hierarchy Process (AHP), Delphi technique, and Monte Carlo Simulation (Abu Qalbin et al., 2023; Mitikie et al., 2017; Erdenekhuu et al., 2022; Alawneh et al., 2024). These methods help understand the relationships and relative importance of risk factors affecting project success criteria like time, cost, quality, safety, and profit. Acknowledging the interdependence of risks is also important for effective management (Adedokun et al., 2023).

While the significance of environmental risks in construction is established and various risk assessment methods are utilized broadly in the field (Erdenekhuu et al., 2022; Alawneh et al., 2024), a focused and in-depth analysis of Environmental Risk Factors (ERFs) within the specific context of high-rise building construction projects in urban developing areas like Addis Ababa is still required. High-rise buildings, with their inherent complexity in structure and process, often present unique environmental challenges. Consequently, a critical step for developing targeted management strategies and enhancing project sustainability involves understanding the causal interrelationships among these ERFs and prioritizing them based on their overall influence and net causal impact. This study aims to address this by employing the Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology. This approach facilitates a comprehensive causal analysis and prioritization of ERFs affecting high-rise building construction in Addis Ababa, leveraging these insights to inform the development of a targeted strategic management framework for these critical risks.

1.2 Statement of the Problem

The accelerated urbanization and economic expansion in Addis Ababa, Ethiopia, have catalyzed a substantial increase in construction activities, notably high-rise buildings (Negesa, 2022). The construction sector plays a pivotal role in national economies, including Ethiopia's, by fostering economic growth, creating employment, and developing essential infrastructure (Tessema et al., 2022; Adedokun and Egbelakin, 2024). However, construction projects are inherently fraught with diverse risks throughout their lifecycle, capable of emerging at any project phase (Abu Qalbin et al., 2023; Alawneh et al., 2024; Adedokun et al., 2023).

Among these multifarious risks, ERFs present a significant, yet frequently inadequately addressed, challenge (Adedokun et al., 2023). Effective risk management is paramount for construction entities to mitigate uncertainties and achieve core project objectives related to time, cost, and quality (Kivrak and Udan, 2023). Concurrently, the construction industry exerts considerable adverse impacts on the environment, society, and the economy (Erdenekhuu et al., 2022). Consequently, assessing the environmental impacts of construction is imperative for promoting sustainability and safeguarding the environment, with environmental management during construction being a key tenet of sustainable development (Abramyan, 2016).

Despite the recognized significance of robust risk management (Kivrak and Udan, 2023), its practical application faces challenges, particularly within developing nations like Ethiopia, where it often remains nascent or confined to limited aspects of project management (Kivrak and Udan, 2023; Mitikie et al., 2017; Teferi and Mamo, 2021; Tessema et al., 2022). Research investigating risk management practices within Ethiopian construction projects remains limited (Kivrak and Udan, 2023), underscoring the need for comprehensive understanding, systematic analysis, and effective prioritization of pertinent risk factors (Adedokun et al., 2023).

The repercussions of failing to adequately identify, analyze, and prioritize these risk factors are severe (Maseko, 2017), often manifesting as project delays and cost overruns (Negesa, 2022). Such risks compromise project standards, budgets, and completion timelines, frequently leading to project goal failures (Maseko, 2017). Indeed, substantial time and cost overruns are documented in Addis Ababa's construction sector (Negesa, 2022), with environmental risks specifically cited as contributors to project delays (Adedokun et al., 2023). Beyond these metrics, unmanaged environmental impacts, such as waste generation, excessive material consumption, and pollution, can lead to environmental contamination, public health concerns, and land degradation (Adedokun et al., 2023; Tafesse, 2021). The inherent complexity and uncertainty in construction, including aspects of green sustainability, further complicate effective risk assessment (Erdenekhuu et al., 2022; Kivrak and Udan, 2023), especially considering that risks are often interdependent and require approaches that address subjectivity (Adedokun et al., 2023; Adedokun and Egbelakin, 2024).

Specifically concerning the burgeoning high-rise building construction in Addis Ababa, critical knowledge gaps persist within the existing literature. Firstly, there is a lack of focused analysis dedicated to identifying the specific ERFs pertinent to high-rise projects within this unique urban context. While general environmental concerns in construction are acknowledged, a targeted identification for this building typology and location remains underexplored. Secondly, the causal interrelationships and influence levels (prominence and relation) among these potential ERFs have not been systematically determined for Addis Ababa's high-rise sector. Understanding these interdependencies is crucial for effective risk management, yet such detailed analysis, particularly using methods like Fuzzy DEMATEL, is not apparent in the available sources for this specific setting.

Thirdly, a robust methodology to prioritize these ERFs based on their overall influence (prominence) and net causal effect (relation), accommodating inherent uncertainty and subjective expert judgments, has not seen widespread application in this domain within

Addis Ababa. While risk prioritization is essential, the application of techniques like Fuzzy DEMATEL to establish such a prioritized list for environmental risks in this context is not evident. Consequently, a tailored strategic framework for managing the most critical ERFs impacting Addis Ababa's high-rise building construction sector, informed by such an analysis, is currently deficient.

Therefore, this research endeavors to address this multifaceted problem through a comprehensive causal analysis and prioritization of environmental risk factors pertinent to high-rise building construction projects in Addis Ababa. The study will employ the Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology. This approach is designed to elucidate the causal relationships among ERFs and to prioritize them based on their influence, thereby facilitating the development of a strategic framework for their effective management. Such an investigation is deemed essential for enhancing project performance, fostering sustainable construction practices, and contributing to more resilient urban development in Addis Ababa.

1.3 Research Questions

The research questions of this study include the following:

- What are the key Environmental Risk Factors (ERFs) pertinent to high-rise building construction projects in Addis Ababa?
- What are the causal interrelationships and influence levels (prominence and relation)
  among the identified ERFs?
- How can the identified ERFs be prioritized based on their overall influence and causal relationships as determined by Fuzzy DEMATEL?

  How can the causal interrelationships and influence levels of critical Environmental Risk Factors inform the development and validation of a targeted strategic management framework for high-rise building construction projects in Addis Ababa?

1.4 Objective of the Study

1.4.1 General Objective

The general objective of the study is to conduct a comprehensive causal analysis and prioritization of Environmental Risk Factors (ERFs) affecting high-rise building construction projects in Addis Ababa using the Fuzzy DEMATEL methodology, and to leverage these insights to inform the development of a targeted strategic management framework.

1.4.2 Specific Objectives

The specific objectives of the study are:

- To identify the key Environmental Risk Factors (ERFs) pertinent to high-rise building construction projects in Addis Ababa.
- To determine the causal interrelationships and influence levels (prominence and relation) among the identified ERFs using the Fuzzy DEMATEL technique.
- To prioritize the identified ERFs based on their overall influence (prominence) and net causal effect (relation) as determined by the Fuzzy DEMATEL analysis.
- To develop and validate a targeted strategic management framework for the critical environmental risk factors, identified and prioritized based on their causal interrelationships and influence levels, for high-rise building construction projects in Addis Ababa.

1.5 Significance of the Study

This research holds considerable significance across theoretical, practical, and policy domains. Firstly, it makes a substantial Contribution to Knowledge in Environmental Risk Management in Construction by systematically identifying, analyzing causal interdependencies, and prioritizing Environmental Risk Factors (ERFs) specifically within the context of high-rise building projects in a developing urban center. The application of the Fuzzy DEMATEL methodology to this specific problem provides a nuanced understanding of the systemic nature of these risks, moving beyond simple risk listings to reveal complex cause-and-effect relationships, such as the pivotal role of regulatory enforcement. Secondly, the study offers significant Practical Implications for

Stakeholders in Addis Ababa's Construction Sector. The validated list of prioritized ERFs and the developed strategic management framework provide project managers, developers, consultants, and contractors with an empirically grounded tool to enhance their environmental risk management practices, potentially leading to improved project performance, reduced negative environmental impacts, and enhanced health and safety.

Thirdly, the findings yield pertinent Policy Recommendations for Urban Development and Environmental Protection in Addis Ababa and similar contexts. The identification of critical dispatcher ERFs, particularly those related to regulatory frameworks and site assessments, furnishes policymakers and regulatory bodies with clear focal points for intervention, highlighting areas where policy adjustments and enhanced enforcement can yield the most significant improvements in environmental performance within the rapidly expanding high-rise construction sector.

1.6 Scope of the Study

The scope of this investigation is clearly delineated to ensure a focused and in-depth analysis. The geographical scope is confined to Addis Ababa, the capital city of Ethiopia, selected due to its significant and ongoing high-rise construction activities and associated environmental challenges. The sectoral scope is specifically high-rise building construction projects, as defined by prevailing local standards (e.g., buildings exceeding a certain number of stories, as per FDRE Directive 649/2021), recognizing the unique environmental risk profile associated with such complex vertical developments in urban areas.

Finally, the methodological scope centers on an integrated Fuzzy DEMATEL approach. This encompasses the identification of ERFs through literature review and expert consultation, the collection of expert judgments on pairwise ERF influences, the application of Fuzzy DEMATEL for causal analysis and prioritization, and the subsequent development of a strategic management framework based on these analytical outcomes.

1.7 Limitations of the Study

While this research was conducted with methodological rigor, certain limitations are acknowledged. Firstly, there were Limitations in relation to the sample size of experts and data accessibility. Although a panel of thirteen experts with significant and diverse experience was engaged, a larger sample size might have provided broader perspectives, though potentially at the cost of the in-depth engagement facilitated by a focused group. Access to extensive, quantifiable historical project data for impact assessment also remained a constraint, common in many developing country contexts. Secondly, despite the use of fuzzy set theory to manage ambiguity, an element of Subjectivity inherent in expert judgments persists.

The DEMATEL outputs are contingent upon the perceptions and experiences of the participating experts. Thirdly, the findings are dependent on the quality and representativeness of the expert panel. While efforts were made to ensure a diverse and knowledgeable panel, the perspectives captured are those of the selected group and may not encompass every possible viewpoint within the Addis Ababa construction sector. Lastly, Scope limitations mean that the findings and the developed framework are primarily specific to high-rise building construction projects in Addis Ababa. While insights may be transferable, direct applicability to other geographical contexts or different types of construction projects would require further validation and adaptation.

1.8 Structure of the Paper

This thesis is organized into five distinct chapters to systematically present the research process and its outcomes. Chapter One introduces the study, outlining the background, problem statement, research questions, objectives, significance, scope, limitations, and the overall structure of the paper. Chapter Two provides a comprehensive Literature Review, exploring existing knowledge on environmental risk factors in construction, risk management practices, the specifics of high-rise building challenges, the Ethiopian construction context, and relevant MCDM techniques, culminating in the identification of research gaps. Chapter Three details the Research Methodology, explaining the research design, study area, data collection procedures, the Fuzzy DEMATEL application steps, framework development process, data analysis software, and measures taken to ensure reliability, validity, and ethical conduct.

Chapter Four presents the results and discussion, including the profile of the expert panel, the identified and validated ERFs, the detailed outcomes of the Fuzzy DEMATEL analysis (including causal interrelationships and prioritization), and the development and validation of the strategic management framework, along with a synthesis of these findings in relation to existing literature. Finally, Chapter Five offers the Conclusion and Recommendations, summarizing the key findings in relation to the research objectives, providing actionable recommendations for stakeholders, and suggesting avenues for future research based on the study's limitations and outcomes.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents a comprehensive review of existing literature pertinent to the analysis and prioritization of environmental risk factors (ERFs) in high-rise building construction projects. The primary aim is to establish a robust theoretical and contextual foundation that underpins the research methodology and informs the subsequent analysis, particularly in identifying key ERFs and understanding the application of advanced decision-making techniques for risk assessment in the specified context.

The review commences by exploring the fundamental concepts of risk and risk management within the broader construction industry (Section 2.2), thereby establishing a general understanding of risk phenomena. It then narrows its focus to Environmental Risk Factors (ERFs) specifically (Section 2.3), examining common categories and their documented impacts on construction projects. Given the specific scope of this thesis, the unique environmental challenges and ERFs intrinsically associated with high-rise building construction are then discussed in detail (Section 2.4). To ground the study in its geographical and operational setting, the review subsequently delves into the specifics of the construction industry in Ethiopia, with a particular focus on Addis Ababa, covering aspects such as current environmental regulations, prevailing practices, and pertinent environmental issues (Section 2.5). Furthermore, an overview of Multi-Criteria Decision-Making (MCDM) techniques, with an emphasis on the Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Fuzzy Analytic Hierarchy Process (AHP) methods as applied to risk management, is presented (Section 2.6). This section is critical for understanding the integrated methodological approach adopted in this research.

By systematically examining these areas, this chapter aims not only to synthesize existing knowledge but also to identify pertinent research gaps (Section 2.7) that this study seeks to address. Ultimately, this literature review serves as a critical precursor to the development of the conceptual framework (Section 2.8) and the empirical investigation into analyzing and prioritizing ERFs affecting high-rise building construction projects in Addis Ababa, thereby directly supporting the specific objectives of this thesis.

2.2 Concepts of Risk and Risk Management in Construction Projects

Construction projects are widely recognized as inherently risky undertakings (Adedokun et al., 2023). Their dynamic and complex nature, coupled with factors such as long duration, complicated processes, involvement in potentially "offensive" environments, heterogeneous financial intensities, and dynamic organizational structures, expose them to numerous dangers (Alawneh et al., 2024). Construction projects are unique, typically built only once, and operate in open and often uncontrolled environments, which contributes to their complexity and risk profile (Maseko, C. M. (2017).

Risk is a significant factor that can appear at any stage of a project, from pre-bidding through planning, design, execution, implementation, and handing over (Maseko, 2017). It is considered a main source of unsuccessful projects and, while it can be handled, minimized, shared, transferred, or accepted, it cannot be ignored (Mitikie et al., 2017). Given the challenges posed by an uncertain world and the potential for risks to detrimentally impact successful project completion, effective risk management is essential for achieving set goals and improving overall project performance (Adedokun et al., 2023). Project management itself is argued to be intrinsically linked with risk management, functioning as a complementary process (Teferi and Mamo, 2021).

2.2.1 Definitions of Risk

Within the context of construction projects, risk is commonly defined as an uncertain event or condition that, should it occur, can have either a positive or a negative effect on one or more project objectives (Alawneh et al., 2024). Some sources emphasize that risk, unlike pure uncertainty, is measurable (Maseko, 2017). Risks can manifest in various forms and originate from different sources, often broadly classified as either internal or external (Kivrak and Udan, 2023).

Internal risks arise from the specific nature of the project itself and are generally considered to be within the control of the project team, affecting parties such as owners, designers, contractors, subcontractors, and suppliers (Tessema et al., 2022). External risks, on the other hand, originate from outside the project's direct scope and are typically beyond the control of the project team (Kivrak and Udan, 2023). These external factors can be unpredictable and not readily foreseeable (Kassem et al., 2020).).

Risks can also be categorized based on their duration (short or long term) or their nature (avoidable or unavoidable) (Maseko, 2017).). Comprehensive classification systems have identified numerous risk factors grouped into various categories, such as technical, construction, financial, socio-political, physical, organizational, environmental, and other risks (Maseko, 2017). Other classifications include legal risks, design risks, management risks, material risks, safety risks, social and cultural risks, and nature risks (Kivrak and Udan, 2023). For example, environmental risks specifically relate to the probability and consequence of adverse environmental impacts resulting from construction activities, such as pollution, resource depletion, and impacts on health (Adedokun et al., 2023).

2.2.2 Risk Management Process

Risk management in construction projects involves a logical sequence of procedures aimed at planning, executing, and monitoring actions to ensure project implementation stays within defined constraints such as time, cost, and quality (Alawneh et al., 2024). It is crucial for enhancing the chances of project success, as risk occurrences are seen as almost always inevitable (Adedokun et al., 2023).

The process typically begins with risk identification, which involves determining the various potential risks that could affect the project (Mitikie et al., 2017). Methods for identifying risks can include systematic literature reviews, consultation with experts, questionnaire surveys, checklists, risk breakdown structures (RBS), brainstorming sessions, and drawing upon experience from previous projects (Adedokun et al., 2023; Adedokun and Egbelakin, 2024).

Following identification is risk assessment, where the characteristics of the identified risks are evaluated (Mitikie et al. 2017). This often involves estimating the probability of a risk occurring and the severity or impact of its consequences on project objectives, such as time, cost, and quality (Erdenekhuu et al., 2022; Abu Qalbin et al., 2023). While qualitative methods based on expert knowledge and subjective judgment have been conventionally used, quantitative methodologies are increasingly adopted for their potential to provide more realistic and accurate analyses and enable higher generalization, particularly for developing quantified models and handling uncertainty (Kim et al., 2021). Specific quantitative techniques mentioned in the literature include the Relative Importance Index (RII), Analytic Hierarchy Process (AHP), Expected Monetary Value (EMV), Monte Carlo Simulation (MCS), Factor Analysis (FA), and regression modeling (Tessema et al., 2022; Negesa et al., 2022; Alawneh et al., 2024).

Risk response or treatment involves planning actions to address identified risks, which can include strategies such as minimizing the potential impact, transferring the risk to another party, sharing the risk, or accepting the risk (Alawneh et al., 2024). The risk management process should be continuous, involving monitoring and control throughout the entire project lifecycle, from the initial phases through to completion (Adedokun et al., 2023). Effectively managing risks is crucial for mitigating adverse impacts and achieving project goals, particularly in contexts where standard practices may be deficient (Kivrak and Udan, 2023). Identifying the underlying causes of risks is seen as essential for enabling their reduction or elimination and improving overall project performance (Mitikie et al., 2017).

2.3 Environmental Risk Factors (ERFs) in Construction

2.3.1 Common Categories of ERFs

Environmental factors constitute a significant category of risks in construction projects, distinct from other types such as financial, technical, or management risks (Kassem et al., 2020). These factors are often considered external risks, originating from the macro environment and typically outside the direct control of the project team (Tessema et al., A2022). They can be categorized within broader frameworks like the PESTLE technique, which includes Environmental, Political, Economic, Social, Technological, and Legal factors (Abu Qalbin et al., 2023). Environmental risk itself is defined as the probability and consequence of an undesirable impact resulting from human interventions in natural processes, particularly pertinent in construction activities due to their scale and potential effects on the surrounding environment (Shrivastava et al., 2024). Effective environmental protection is viewed as essential for achieving sustainable development, and assessing the environmental impacts of construction projects is necessary to promote sustainability. However, effectively managing these risks, especially in contexts where standard practices may be deficient or the concept of sustainable construction is relatively new, can be challenging (Erdenekhuu et al., 2023).

Environmental risks encompass a range of factors and potential adverse impacts on various environmental elements and human well-being (Adedokun et al., 2023). Key environmental impact indicators identified in the literature include air, water, and land pollution, water consumption, solid waste, flora and fauna, socio-cultural aspects, and resource consumption (Shrivastava et al., 2024). These factors arise from issues, concerns, and activities that confront a project during its execution and operational life (Adedokun et al., 2023). Specific adverse effects of building construction projects on the environment are widely discussed in the sources. These include biological diversity losses, often due to raw material extraction (Adedokun and Egbelakin, 2024), resource depletion, also linked to extraction and consumption (Tafesse et al., 2022), and landfill problems resulting from significant waste generation (Islam et al., 2024).

Construction activities are known to generate substantial amounts of waste, including construction and demolition (C&D) waste, which has detrimental impacts on the environment and human health (Teferi, 2017). Problems associated with construction waste management, such as insufficient strategies and inadequate disposal, contribute to environmental pollution and excessive consumption of raw materials (Tafesse et al., 2022). Furthermore, environmental risks can directly impact human health and safety through factors like poor air quality, lack of supply of potable water, and inadequate sanitation facilities (Adedokun and Egbelakin, 2024). The energy consumed during the extraction and transportation of raw materials also contributes significantly to the generation of pollution (Adedokun et al., 2023).

Beyond pollution and resource issues, environmental risks can also stem from interacting with the natural conditions of the project site. Choosing unsuitable locations without considering potential natural hazards like flood zones, landslide-prone areas, or seismic activity can introduce risks (Porzionato, 2023). Thorough site assessments and proper site planning are highlighted as ways to reduce vulnerabilities related to the natural environment (Porzionato, 2023). In some contexts, unforeseen site conditions, which can include geological or pollution-related issues, are also recognized as construction risks that may have environmental implications (Adedokun et al., 2023; Tessema et al., 2022).

Moreover, the increasing focus on sustainable and green building practices introduces a set of related risks, particularly in regions where these approaches are nascent (Tessema et al., 2022). Challenges such as complex permit procedures, the potential for overlooked high initial costs associated with green technologies, unclear owner requirements for sustainable features, and a lack of availability of green materials and equipment can pose crucial risks for sustainable construction projects (Erdenekhuu et al., 2022). Higher costs for eco-friendly materials and equipment can act as barriers to adopting new techniques aimed at mitigating environmental impacts (Shrivastava and Dwivedi, 2024).

The impact of environmental risk factors is not limited to the natural environment itself; they can significantly affect project objectives and success criteria. Environmental risks have been found to have a notable impact on factors like project completion time and cost (Adedokun et al., 2023), potentially leading to delays (Adedokun and Egbelakin, 2024). They also influence safety performance (Adedokun and Egbelakin, 2024), project profit (Adedokun and Egbelakin, 2024), and end-user satisfaction (Adedokun et al., 2023). For instance, environmental risks influencing project time could lead to delays, increasing construction costs and potentially impacting the project's financial viability and the ability to meet deadlines for stakeholders (Adedokun and Egbelakin, 2024). Controlling pollution from construction activities and ensuring proper access to the site are practical measures related to managing environmental risks (Adedokun et al., 2023).

While environmental risks are universally acknowledged, their perceived importance can vary geographically (Tessema et al., 2022). Studies in different regions show varying rankings for environmental factors compared to other risk categories (Maseko, 2017). In the context of Ethiopia, the construction sector is recognized as facing challenges, including those related to risk management (Mitikie et al., 2017). Construction waste management, a direct environmental issue, is a significant concern in Ethiopia, with challenges identified in Addis Ababa specifically, including inadequate waste disposal strategies and associated economic and environmental impacts (Tafesse, 2021). The relatively new concept of sustainable construction in Ethiopia and the low degree of its adoption due to various obstacles, including risks, underscore the relevance of analyzing environmental risks in this context (Tessema et al., 2022). Identifying the specific environmental risk factors pertinent to high-rise building construction in Addis Ababa and understanding their significance is therefore a critical step towards improving project performance and promoting sustainable development in the region.

In summary, based on the extant literature reviewed, environmental-related risk factors (ERFs) impacting construction project success and performance have been identified and categorized. These risks can arise from various sources, including external environmental conditions, natural phenomena, site-specific issues, and the environmental consequences of construction activities themselves. Managing these risks is crucial for project success (Adedokun et al., 2023). The existing literature discusses environmental risks in different contexts, such as oil and gas projects (Kassem et al., 2020), projects funded by external sources (Abu Qalbin, 2023), education building projects (Adedokun et al., 2023), sustainable construction projects (Erdenekhuu et al., 2022), and construction projects in general (Abd El-Karim et al., 2017). Table 2.1 provides a comprehensive overview of different categories and specific environmental-related risk factors discussed in the literature.

Table 2.1: Environmental-Related risk factors in construction

Specific Environmental Risk Factor	**Source(s)**
Category 1: Environmental Risks (General & Regulatory)	
Environmental Risk / Concerns (as a broad category)	Adedokun and Egbelakin, 2024; Adedokun et al., 2023; Abu Qalbin et al., 2023; Ansah et al., 2016; Kivrak and Udan, 2023; Maseko, 2017; Tessema et al., 2022
Environmental Protection Pressure	Alfadil et al., 2022
Environmental Hazards of the Project	Bahamid et al., 2019
Environmental Regulations and Permitting Procedures	Bahamid et al., 2019; Erdenekhuu et al., 2022
Project Affects Employees' Health	Nguyen et al., 2021

(environmental causes)	
Natural Phenomena / Weather Risks	
Natural Phenomena / Extreme Weather / Force Majeure Events (general)	Alfadil et al., 2022; Kassem et al., 2020; Nguyen et al., 2021; Tessema et al., 2022
Adverse / Unexpected Weather Conditions (general)	Alfadil et al., 2022; Bahamid et al., 2019; Dong et al., 2025; Schuldt et al., 2021; Tessema et al., 2022
Rain / Precipitation (including prolonged)	Nguyen et al., 2021; Schuldt et al., 2021
Storms	Nguyen et al., 2021; Schuldt et al., 2021
Temperature Extremes/Variations	Schuldt et al., 2021
Humidity Extremes/Variations	Schuldt et al., 2021
Wind (including strong winds as natural phenomena)	Mitikie et al., 2017; Schuldt et al., 2021
Climate Change Impacts	Tessema et al., 2022
Flood	Kassem et al., 2020
Fire (natural, e.g., wildfire)	Kassem et al., 2020
Landslip / Landslide	Alfadil et al., 2022; Mitikie et al., 2017
Earthquake	Mitikie et al., 2017
Site-Specific Environmental & Physical Risks	
Unforeseen / Differing Site Conditions (DSC), including unforeseen circumstances	Alfadil et al., 2022; Amarasekara et al., 2018; Amarasekara, Perera, & Rodrigo, 2018; Kassem et al., 2020; Tessema et al., 2022
Adverse Geological Conditions (site-related)	Adedokun et al., 2023
Site Contamination / Pollution-related Conditions (site-related)	Adedokun et al., 2023
Difficulty Accessing Site (due to environmental/site conditions)	Adedokun et al., 2023
Environmental Impacts & Resource-Related Risks	

Pollution from Construction Activities (general, including discharge of chemicals/materials)	Adedokun et al., 2023; Nguyen et al., 2021; Tafesse et al., 2022
Air Pollution (increase)	Erdenekhuu et al., 2022
Water Pollution (increase)	Erdenekhuu et al., 2022
Land Pollution (increase)	Erdenekhuu et al., 2022; Shrivastava and Dwivedi, 2024
Noise Pollution	Erdenekhuu et al., 2022; Shrivastava and Dwivedi, 2024
Increased Resource / Raw Material Consumption	Shrivastava and Dwivedi, 2024; Tafesse et al., 2022
Increased Water Consumption	Erdenekhuu et al., 2022
Waste Generation, Management & Disposal Issues	Alfadil et al., 2022; Erdenekhuu et al., 2022; Shrivastava and Dwivedi, 2024; Tafesse et al., 2022; Yusof et al., 2017
Impact on Flora and Fauna	Shrivastava and Dwivedi, 2024
Socio-cultural Impact (from environmental disruption)	Shrivastava and Dwivedi, 2024
Public Health and Safety Risks (from waste, pollution, etc.)	Alfadil et al., 2022; Tafesse et al., 2022
Challenges with Green/Eco-friendly Materials & Equipment:	
Lack of Availability	Erdenekhuu et al., 2022
High Costs / Barrier to Adoption	Shrivastava and Dwivedi, 2024

2.3.2 Impacts of ERFs on Construction Projects

Environmental related risk factors (ERFs) in construction are not merely theoretical constructs; their occurrence can translate into significant adverse impacts on various aspects of a project's execution and outcome, as well as the broader environment and society (Abu Qalbin et al., 2023). Construction projects are inherently susceptible to a range of risks that can negatively affect crucial performance indicators such as cost, time, quality, and safety (Adedokun et al., 2023). Environmental risks, arising from factors like natural conditions, pollution, or regulatory requirements, contribute substantially to these negative consequences (Abu Qalbin et al., 2023). Effective risk management is essential for achieving project goals and mitigating these detrimental effects (Alawneh et al., 2024).

Prominently, environmental risks can lead to project time and cost overruns (Bahamid et al., 2019). Factors such as adverse weather conditions (Tessema et al., 2022), unforeseen site conditions like geological or pollution-related issues (Amarasekara et al., 2018), or challenges in waste management (Teferi, 2017). can directly cause delays in work progress (Adedokun and Egbelakin, 2024). Delays, in turn, often result in increased construction costs, potentially amplified by factors like inflation (Adedokun and Egbelakin, 2024). Research indicates that environmental risk factors can significantly impact project completion time, with this influence potentially leading to cascading effects such as increased costs due to delays (Adedokun and Egbelakin, 2024). While some studies specifically found environmental risk factors to significantly impact completion to cost (Adedokun et al., 2023), others using different analytical methods suggest the impact on cost might be indirect, primarily through resulting delays (Adedokun and Egbelakin, 2024). Differing site conditions have been identified as a significant factor contributing to both delays and cost overruns, with a notably high impact on project duration (Amarasekara et al., 2018).

Beyond time and cost, environmental risks also influence project quality and safety performance (Abu Qalbin et al., 2023). The sources note that environmental factors can directly impact human health and safety on construction sites (Islam et al., 2024). Specific issues highlighted include the adverse effects on human health due to poor air quality, lack of potable water supply, and inadequate sanitation facilities (Shrivastava and Dwivedi, 2024). Environmental risks were found to have a significant influence on project safety performance in one study (Adedokun and Egbelakin, 2024), suggesting that inadequate management of environmental factors can compromise site safety. Furthermore, environmental risks, alongside design risks, have been shown to significantly impact project quality or adherence to standards (Adedokun et al., 2023).

Lack of essential resources, which can be linked to environmental considerations like raw material availability or logistics, can also affect construction quality (Mitikie, et al., 2017).

The ripple effects of environmental risk materialization extend to project profitability and end-user satisfaction (Tafesse et al., 2022). Delays and cost increases driven by environmental issues inherently reduce project profit (Adedokun et al., 2023). Environmental risks, specifically, were identified as having a significant impact on project profit in some analyses (Adedokun and Egbelakin, 2024). A reduction in profit due to unexpected costs or delays can pressure contractors, potentially leading to substandard work or even project abandonment, negatively affecting project success (Adedokun and Egbelakin, 2024). Environmental risks, when coupled with legal and management factors, were also found to significantly influence the satisfaction levels of the project's end-users (Adedokun et al., 2023).

The impacts of environmental risks are not confined to the project site and its immediate stakeholders; they also have profound consequences for the natural environment and public health (Erdenekhuu et al., 2022). Construction activities are associated with significant environmental pollution, including air, water, and land contamination (Islam et al., 2024). This pollution often stems from issues like inefficient waste management and disposal strategies (Teferi, 2017). The energy consumed during material extraction and transportation also contributes substantially to pollution generated by the building industry (Adedokun and Egbelakin, 2024). Environmental risks can lead to excessive consumption of raw materials and resource depletion (Yusof et al., 2017), highlighting unsustainable practices often exacerbated by inadequate environmental management (Tafesse, 2021). Issues like substantial construction and demolition (C&D) waste generation lead directly to landfill problems and pose detrimental impacts on the environment and human health (Islam et al., 2024). Adverse effects on biological diversity and flora/fauna resulting from activities like raw material extraction or general construction impacts on the land are also critical environmental consequences (Adedokun et al., 2023). Beyond the direct natural environment, environmental risks and construction impacts also touch upon socio-cultural aspects and the well-being of the wider society, affecting elements such as the perception of the general atmosphere or impacts related to resource use and waste (Adedokun et al., 2023).

Furthermore, managing environmental risks involves navigating legal and regulatory landscapes, and challenges in this area can impact project execution (Erdenekhuu et al., 2022). Difficulties in obtaining necessary environmental permits and licenses or ambiguity in work legislation related to environmental requirements constitute legal risks that can delay or complicate projects (Abu Qalbin et al., 2023). Complex permit procedures, particularly for projects incorporating sustainable or green building practices, are identified as crucial risks (Erdenekhuu et al., 2022). The absence of appropriate legal frameworks can also hinder the adoption of techniques aimed at mitigating environmental impacts (Tessema et al., 2022).

In summary, environmental related risk factors in construction projects have a wide array of impacts, affecting not only the core project performance metrics of time, cost, quality, safety, and profitability, but also influencing end-user satisfaction, contributing to significant environmental pollution, depleting resources, impacting biodiversity, posing risks to human health and safety, and presenting legal and regulatory challenges (Erdenekhuu et al., 2022). Recognizing and understanding these multifaceted impacts is crucial for developing effective strategies to manage environmental risks and promote sustainable construction practices, especially in contexts like Addis Ababa where the concept of sustainable construction is still developing (Tessema et al., 2022).

2.4 High-Rise Building Construction - Specific Environmental Challenges

High-rise building construction projects, by their nature of scale, complexity, and location typically within dense urban environments like Addis Ababa, present a unique set of environmental challenges and associated risks that distinguish them from lower-rise or less complex construction endeavors (Alawneh et al., 2024). While general construction activities inherently impact the environment through resource consumption, waste generation, and emissions (Adedokun et al., 2023), the magnitude and specific characteristics of high-rise projects can amplify these impacts and introduce additional environmental concerns that require specialized consideration (Erdenekhuu et al., 2022). The concentration of materials, labor, and equipment on a limited footprint, coupled with the significant structural demands and extended project durations, contribute to a distinct profile of environmental risk factors (ERFs) that must be rigorously analyzed and managed for successful project delivery and overall sustainability (Alawneh et al., 2024). Effective risk management, including the identification, assessment, and mitigation of these ERFs, is paramount for achieving project objectives concerning time, cost, quality, and safety, particularly in developing contexts where the concept of sustainable construction may still be evolving (Bahamid et al., 2019).

2.4.1 Unique ERFs associated with high-rise structures

The inherent characteristics of high-rise building construction contribute to specific environmental risk factors or significantly amplify the impact of general environmental risks compared to conventional building projects. One critical area relates to site conditions and geology, particularly concerning foundations. While differing site conditions, such as unforeseen geological or physical obstructions, are general risks in construction projects that can lead to delays and cost overruns (Adedokun et al., 2023), the immense structural loads transferred by high-rise buildings make the accurate assessment and handling of complex soil structures and subsurface conditions exceptionally critical (Adedokun et al., 2023). Issues like poorly recognized soil structure or unforeseen geological challenges, though not explicitly linked *only* to high-rise in the sources, would have compounded implications for the stability and safety of tall structures (Adedokun et al., 2023). Conducting thorough site assessments to identify potential hazards like unstable ground or seismic activity is crucial for any construction (Porzionato, 2023), but becomes even more vital and technically challenging for high-rise foundations.

Waste generation represents another significant environmental concern that is amplified in high-rise construction. Construction and demolition (C&D) waste is a major source of pollution and environmental detriment in the building industry (Tafesse, 2021). High-rise projects, due to their sheer volume of materials and construction activities over extended periods, generate substantially larger quantities of waste (Tafesse et al., 2022). Inefficient waste management strategies, which are noted as a problem in the Ethiopian construction sector (Crawley et al., 2019), can lead to significant landfill problems, pollution, and adverse impacts on the environment and human health when dealing with the large volumes typical of high-rise projects (Islam et al., 2024). The scale of waste generation directly impacts the environment through the discharge of chemicals and materials and contributes to the excessive consumption of raw materials and resource depletion (Tafesse et al., 2022).

Energy consumption during the construction phase, particularly for the extraction and transportation of raw materials, contributes significantly to pollution generated by the building industry (Adedokun and Egbelakin, 2024). High-rise buildings require vast amounts of materials like concrete, steel, and glass, the production and transport of which are energy-intensive. While the sources discuss energy use as an environmental performance indicator generally (Erdenekhuu et al., 2022), the sheer quantity of materials involved in high-rise construction escalates this impact, although the sources do not explicitly identify this as a *unique* ERF solely for high-rise as opposed to other large-scale projects.

Other environmental factors, while not exclusive to high-rise, can have distinct implications. Weather conditions, including adverse weather (Amarasekara et al., 2018), can cause significant delays. For high-rise construction, working at significant heights exposes projects to greater wind effects and other atmospheric conditions, which can affect structural activities and site safety, although specific risks related to wind loads on the structure during construction or operation are not detailed as a unique high-rise ERF in the provided sources (Schuldt et al., 2021). Site access difficulties, noted as a risk factor (Tessema et al., 2022), can be particularly pronounced for large high-rise projects in congested urban settings like Addis Ababa, complicating logistics and potentially increasing vehicle emissions and local environmental disturbance. Legal and regulatory risks, such as difficulties in obtaining environmental permits and licenses (Adedokun et al., 2023), can also be more complex and time-consuming for large, high-impact high-rise developments (Erdenekhuu et al., 2022).

It is important to note that while the provided sources discuss various environmental risks in construction generally, or risks in high-rise projects (such as delay risks Alawneh et al., 2024), they do not always explicitly isolate environmental risk factors that are *unique* to high-rise structures compared to other large building projects. The discussion above highlights how the scale and characteristics of high-rise can amplify general environmental risks like waste generation, material consumption, and site-specific geological issues. Aspects such as specific structural risks from wind loads or the urban heat island effect are not detailed within the provided source material.

2.4.2 Sustainable construction practices for high-rise buildings

Addressing the significant environmental impacts associated with high-rise construction necessitates the adoption of sustainable construction practices (Abramyan, 2016). Sustainable construction aims to balance environmental, economic, and social considerations throughout the project lifecycle (Papamichael et al., 2023). While the concept of sustainable construction, including its adoption in Ethiopia, is noted as being relatively new or having a low degree of implementation (Tessema et al., 2022), several practices discussed in the sources are applicable and particularly important for high-rise developments.

A primary focus area is waste management, given the substantial volumes generated by high-rise projects (Tafesse et al., 2022). Practices such as waste minimization (through reduction, reuse, and recycling), waste sorting, and implementing strong onsite management practices are crucial for mitigating the environmental impacts of C&D waste (Yusof et al., 2017). Employing a dedicated waste management officer or incorporating waste management into integrated project management are strategies suggested to improve waste efficiency. The use of prefabricated or off-site components can also help reduce onsite waste generation (Tafesse et al., 2022).

The choice and use of building materials are also central to sustainable high-rise construction. This includes the selection of sustainable materials and addressing concerns related to their cost and availability (Erdenekhuu et al., 2022). Sustainable practices involve minimizing the consumption of raw materials and promoting the use of recycled materials to alleviate resource depletion (Adedokun et al., 2023). Research highlights the importance of indicators related to building materials in assessing environmental performance (Erdenekhuu et al., 2022).

Reducing the environmental footprint extends to managing pollution and resource use on site. This involves controlling air, water, and land pollution from construction activities (Tafesse et al., 2022), managing water consumption (Erdenekhuu et al., 2022), and ensuring environmental compliance (Abramyan, 2016). Designing with environmental considerations in mind, including integrating environmental management into the project planning and design phases, is also vital (Yusof et al., 2017). The implementation of green building codes and specifications is identified as a measure to promote sustainable construction and waste reduction (Tafesse et al., 2022). Site selection that considers the natural environment and potential hazards is also a component of resilient and sustainable construction (Porzionato, 2023).

Despite the recognized benefits, the adoption of sustainable construction practices in contexts like Ethiopia faces challenges, including a potential lack of awareness or knowledge among stakeholders (Tessema et al., 2022). Perceived higher costs of eco-friendly materials and equipment can act as a barrier (Shrivastava & Dwivedi, 2024). Furthermore, complex permit procedures for sustainable building projects or a lack of appropriate legal and socioeconomic frameworks can hinder implementation (Erdenekhuu et al., 2022). These barriers highlight the need for increased awareness, training, collaboration, and supportive regulations to facilitate the widespread adoption of sustainable practices in high-rise construction in Addis Ababa (Tessema et al., 2022).

2.5 The Construction Industry in Ethiopia

The construction industry holds a crucial position in the economy of any nation, serving as a key driver for economic growth and development (Adedokun et al., 2023). This sector contributes significantly to the gross domestic product and is instrumental in improving the quality of life through the provision of infrastructure (Adedokun and Egbelakin, 2024). However, construction projects are inherently high-risk activities that can be challenging to manage. Risks, defined as uncertain events with potential positive or negative effects on project objectives (Adedokun and Egbelakin, 2024).), are ever-present and cannot be ignored in construction projects (Alawneh et al., 2024). Effective risk management is therefore critical for achieving project goals related to time, cost, quality, and environmental sustainability (Mitikie et al., 2017).

The construction sector in Ethiopia is particularly challenged by various problems, making efforts to develop the industry difficult and complex (Tessema et al., 2022). This reality necessitates a focused approach to risk management to navigate uncertainties and improve project outcomes (Mitikie et al., 2017). The urban landscape of Addis Ababa, undergoing rapid development, presents a concentrated environment where construction activities are extensive, thereby amplifying the potential environmental impacts (Shrivastava & Dwivedi, 2024). Analyzing the environmental risk factors within this specific context is essential for fostering sustainable construction practices and mitigating adverse effects on the environment (Shrivastava & Dwivedi, 2024).

2.5.1 Overview of the Construction Sector and its Growth

The Ethiopian Construction Industry is recognized as one of the primary engines driving the country's economy, having substantial impacts on the efficiency and productivity across various sectors (Negesa, 2022). The sector is currently experiencing a boom, fueled by the escalating demand for public facilities (Negesa, 2022). This rapid growth of the Ethiopian economy necessitates significant infrastructure and asset development (Tessema et al., 2022). Despite its vital role and growth, the industry faces numerous problems, including common issues such as time and cost overruns, as projects frequently deviate from original contract durations and budgets due to a range of factors (Negesa, 2022).

Studies examining construction projects in Ethiopia, including those in Addis Ababa, have documented considerable time delays, with infrastructure projects experiencing average time delays of 175% and building projects between 50 and 100 million Ethiopian Birr contract amounts seeing delays of 300% (Negesa, 2022). The prevalence of risk factors is considered inherent in construction projects in developing countries, contributing to projects falling below expected success levels (Adedokun and Egbelakin, 2024). The industry's trajectory and challenges in Addis Ababa underscore the importance of understanding specific local contexts when assessing project risks (Teferi and Mamo, 2021).

2.5.2 Current Environmental Regulations and Practices in Addis Ababa

Sustainable development necessitates effective environmental protection, recognizing that human progress is temporary if natural resources are not conserved (Erdenekhuu et al., 2022). Within the construction context, this involves managing risks associated with environmental problems, concerns, and activities throughout the project lifecycle (Adedokun et al., 2023). Legal and regulatory frameworks play a significant role in guiding environmental practices. Risks such as difficulties in obtaining permits and ambiguity regarding work legislation are considered legal risk factors. Environmental and health and safety law are integral components of legal risk in construction (Adedokun et al., 2023).

Despite the recognized importance of environmental protection and the existence of legal frameworks, the concept and adoption of sustainable construction practices are still relatively new in Ethiopia, including in the building sector, with a low degree of implementation. This is partly attributed to various obstacles (Tessema et al., 2022). Challenges to effective sustainable construction and demolition waste management, for instance, include a perceived lack of law enforcement and regulation (Al-Otaibi et al., 2022). Environmental compliance and management are identified as crucial indicators for determining environmental sustainability (Erdenekhuu et al., 2022). However, barriers such as the perceived higher cost for eco-friendly materials and equipment can hinder the adoption of new techniques and technologies (Shrivastava & Dwivedi, 2024).

Furthermore, the lack of appropriate legal and socioeconomic frameworks and complex permit procedures can impede the successful implementation of sustainable building techniques (Tessema et al., 2022). Integrating environmental considerations into project planning, design, and estimation phases through effective risk management processes is necessary to mitigate negative environmental impacts (Shrivastava & Dwivedi, 2024). Increased awareness, training, collaboration, and supportive regulations are needed to promote sustainable practices in the construction industry in Addis Ababa (Tessema et al., 2022).

2.5.3 Environmental Issues in Construction Projects in Addis Ababa

Construction activities inherently impact the environment, and the scale of these activities in rapidly urbanizing areas like Addis Ababa leads to significant environmental effects (Shrivastava & Dwivedi, 2024). Environmental risk encompasses the probability and consequences of undesirable impacts resulting from human interventions in natural processes, including construction (Shrivastava & Dwivedi, 2024). Construction and Demolition (C&D) waste is a major environmental risk factor (Adedokun et al., 2023). The rapid expansion of the construction sector in Ethiopia has led to considerable wastage of construction materials, negatively affecting the environment, society, and economy due to inefficient waste management strategies (Tafesse, 2021). Studies focused specifically on building construction projects in Addis Ababa indicate that construction waste is a significant challenge for a vast majority of ongoing projects (Tafesse et al., 2022). Large quantities of waste, including materials like cement, hollow concrete blocks, reinforcement bars, concrete, and mortars, are generated from both public and private building projects in the city (Tafesse et al., 2022).

The environmental impacts of this waste generation and other construction activities are wide-ranging. They include the pollution of the environment through the discharge of chemicals and other materials, the creation of landfill problems, and the contribution to excessive consumption of raw materials and resource depletion (Tafesse et al., 2022). Other adverse effects on the environment and human well-being cited in the context of construction include biological diversity losses due to raw material extraction, adverse human health outcomes resulting from poor air quality, lack of potable water supply, lower worker productivity, and inadequate sanitation facilities (Adedokun et al., 2023). Energy consumption during material extraction and transportation is a significant source of pollution generated by the building industry (Adedokun et al., 2023). Key environmental impact indicators in sustainable construction projects include air, water, and land pollution, water consumption, and solid waste (Erdenekhuu et al., 2022).

In general, environmental risks in building construction can negatively affect human health, the general atmosphere, ecology, and society (Shrivastava and Dwivedi, 2024). Studies concerning waste management in Addis Ababa specifically aim to identify problems in waste disposal strategies and their consequent economic and environmental impacts (Teferi, 2017). While environmental factors may not be ranked as the top risks in all Ethiopian locations, such as Gondar (Tessema et al., 2022), their significant impact on factors like project completion to cost, standard/quality, and end-user satisfaction has been noted (Adedokun and Egbelakin, 2024). The documented environmental issues in Addis Ababa's construction projects highlight the critical need for effective management strategies to mitigate these impacts and move towards more sustainable practices (Tafesse et al., 2022).

2.6 Multi-Criteria Decision-Making (MCDM) Techniques in Risk Management

Construction projects, particularly large-scale undertakings such as high-rise buildings, are inherently complex due to diverse activities, numerous stakeholders, and dynamic business environments (Jalhoom and Mahjoob, 2024). These projects are exposed to a variety of risk factors that can significantly impact critical aspects like costs, schedules, and overall quality (Chatterjee et al., 2018). Managing these risks effectively is a vital component of the decision-making process in construction projects (Chatterjee et al., 2018). Identifying, evaluating, and assessing project risks in this sector is widely recognized as a challenging task that requires sophisticated decision-making methodologies (Chatterjee et al., 2018).

The evaluation and assessment of construction project risks inherently constitutes a Multi-Criteria Decision Making (MCDM) problem (Chatterjee et al., 2018). MCDM is a decision-making tool designed to integrate both quantitative and qualitative factors when selecting the most suitable option from a set of alternatives based on multiple criteria (Kaya, 2024). Real-world decision problems are typically complex and necessitate the consideration of several conflicting, and sometimes interrelated, criteria. MCDM methods provide frameworks and tools to evaluate options based on multiple characteristics and synthesize potentially contradictory features (Kaya, 2024). These techniques are increasingly utilized for the evaluation of alternatives and comparative analysis in various fields, including engineering and project management (Mardani et al., 2015).

One of the significant challenges in construction risk management is the presence of uncertainty and ambiguity in risk evaluation. This often arises from incomplete information or the subjective judgments of decision-makers (Chatterjee et al., 2018). To address these issues, numerous MCDM methods, including hybrid approaches, have been developed and applied to construction risk assessment and management (Jalhoom and Mahjoob, 2024). Techniques incorporating fuzzy set theory are particularly valuable for handling vague, inconsistent, and subjective data (Salamai, 2025). Fuzzy MCDM methods allow experts to express opinions using linguistic terms or numerical intervals rather than precise numbers, enabling them to deal with uncertainties such as imprecision and fuzziness in the decision process (Tamošaitienė et al., 2013). These fuzzy approaches have become principal techniques for addressing subjectivity in construction risk analysis (Zhao, 2024).

A wide range of MCDM methods have been applied to construction risk assessment and management problems (Tamošaitienė et al., 2013). Among the most frequently employed are the Analytic Hierarchy Process (AHP) and its fuzzy extension, Fuzzy AHP (FAHP) (Mardani et al., 2015). AHP is capable of quantifying the relative priorities of decision alternatives on a ratio scale (Zhao, 2024). FAHP extends this capability to handle vagueness and has been extensively applied in construction safety and risk assessment (Zhu et al, 2021; Chatterjee et al., 2018). Studies have utilized FAHP for assessing safety risks during planning stages (Zhu et al., 2021), comparing it with standard AHP for evaluating potential risk factors (Chatterjee et al., 2018), and incorporating it into hybrid models for construction project risk assessment (Zhu et al., 2021).

Another prominent MCDM technique utilized in construction risk management is the Decision-Making Trial and Evaluation Laboratory (DEMATEL), including its fuzzy variant, Fuzzy DEMATEL (FDEMATEL) (Jalhoom and Mahjoob, 2024). DEMATEL is specifically employed to analyze the interdependencies among risks and to prioritize them (Mardani et al., 2015). For instance, Fuzzy DEMATEL has been developed to prioritize risks associated with construction projects, often structured using a risk breakdown structure (Jalhoom and Mahjoob, 2024). The Fuzzy Grey DEMATEL (FGDEMATEL) approach, which combines fuzzy logic with Grey theory and DEMATEL, has been proposed to handle language ambiguity, uncertainty, and interrelationships between risk categories in construction projects (Jalhoom and Mahjoob, 2024).

Beyond AHP and DEMATEL, other notable MCDM techniques applied in construction risk management include TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and Fuzzy TOPSIS (Zhao, 2024), COPRAS (COmplex PRoportional ASsessment) and Grey COPRAS (COPRAS-G) (Tamošaitienė et al., 2013). ANP (Analytic Network Process) and Fuzzy ANP (Chatterjee et al., 2018), and MABAC (Multi-attributive border approximation area comparison) and D-number extended MABAC (Chatterjee et al., 2018). These methods have been used for various purposes, such as evaluating risks during tunneling operations (Jalhoom and Mahjoob, 2024), assessing international construction projects (Jalhoom and Mahjoob, 2024), prioritizing risks in onshore gas refinery plants (Jalhoom and Mahjoob, 2024), and selecting subcontractors in international projects (Chatterjee et al., 2018).

Hybrid MCDM approaches, which combine two or more methods, are increasingly used to leverage the strengths of different techniques and overcome their individual limitations, particularly in handling complex and uncertain decision environments (Mardani et al., 2015). Examples include hybrid methods combining AHP with TOPSIS (Zhu et al., 2021), DEMATEL with ANP (Zhao, 2024), and integration of fuzzy logic with techniques like FMEA or ANP (Chatterjee et al., 2018). Fuzzy hybrid approaches, such as integrated Fuzzy AHP and Fuzzy TOPSIS methodologies, have been applied for construction project selection and risk assessment (Zhu et al., 2021 The use of D-number theory, which can handle uncertain, incomplete, and ambiguous evaluations, has also been combined with methods like ANP and MABAC in hybrid frameworks for prioritizing construction project risks and selecting mitigation strategies (Chatterjee et al., 2018).

The selection of risk response strategies, often viewed as a multi-objective optimization problem, can also be effectively addressed using MCDM techniques (Zhao, 2024). MCDM methods provide valuable frameworks for systematically identifying, evaluating, prioritizing, and managing the diverse risks encountered throughout the lifecycle of construction projects (Chatterjee et al., 2018). Their ability to incorporate multiple conflicting criteria, handle uncertain and subjective information (especially with fuzzy extensions), and analyze interdependencies among risks makes them powerful tools for informing robust decision-making processes in this challenging domain (Jalhoom and Mahjoob, 2024).

In summary, the application of MCDM techniques, particularly those integrating fuzzy set theory and forming hybrid approaches, offers a structured and systematic way to navigate the complexities and uncertainties inherent in construction risk management (Mardani et al., 2015). These methodologies provide robust tools for risk assessment, prioritization, and the selection of appropriate mitigation strategies, contributing to the successful delivery of construction projects (Chatterjee et al., 2018). Their increasing use reflects their recognized value in addressing the multifaceted nature of risks in the built environment (Zhao, 2024).

2.7 Research Gaps Identifications

This thesis aims to conduct a comprehensive causal analysis and prioritization of environmental risk factors (ERFs) affecting high-rise building construction projects in Addis Ababa, Ethiopia, utilizing the Fuzzy DEMATEL methodology to inform the development of targeted management strategies. Based on a review of the provided sources, several research gaps can be identified that this study is specifically designed to address. While the literature acknowledges the vulnerability of construction projects to various risks throughout their lifecycle, including external factors such as environmental ones, and highlights the potential negative impacts risks can have on project outcomes like cost, time, and quality, certain critical areas require more focused investigation, particularly within the specified context.

Based on the thesis objectives and the provided sources, the research gaps include:

a) Lack of a specific, focused analysis of ERFs pertinent to high-rise building construction in Addis Ababa.

While the sources acknowledge that construction projects are vulnerable to a range of risks, including environmental factors, and that these constitute a category of external risk, there is a notable absence of detailed, specific research focusing exclusively on environmental risk factors as they pertain to high-rise building construction projects in Addis Ababa (addressing Specific Objective 1). Studies in Ethiopia have identified various influential risk factors impacting project performance and categorize risks into types including environmental, but environmental factors were not always among the highest-ranked risks in broader Ethiopian studies, contrasting with other regions where they might be more dominant. Environmental management in construction is generally considered "heavily underexplored". Research on sustainable construction and construction waste management in Ethiopia discusses environmental impacts but does not specifically zero in on the identification and detailed characterization of ERFs unique to high-rise projects in the capital city.

b) Absence of detailed analysis of causal interrelationships and influence levels (prominence and relation) among ERFs using Fuzzy DEMATEL in this context.

A key objective of this thesis is to determine the causal interrelationships and influence levels (prominence and relation) among the identified ERFs using the Fuzzy DEMATEL technique (addressing Specific Objective 2). While risk identification, assessment (based on probability and impact), and ranking are common themes in the sources, the provided literature does not delve into analyzing the complex causal relationships or the degree of influence one risk factor might have on others using methods like DEMATEL, especially its fuzzy variant. Understanding these interdependencies is crucial for developing effective mitigation strategies, but this specific type of analysis appears to be a less explored area in the sources concerning environmental risks in high-rise construction within Addis Ababa.

c) Limited application of Fuzzy DEMATEL for the prioritization of ERFs based on their overall influence and net causal effect in this specific context.

This study aims to prioritize the identified ERFs based on their overall influence (prominence) and net causal effect (relation) as determined by the Fuzzy DEMATEL analysis (addressing Specific Objective 3). The sources demonstrate the use of various risk assessment and prioritization methods, such as the Relative Importance Index (RII) and Analytic Hierarchy Process (AHP). However, the specific application of Fuzzy DEMATEL to establish a prioritized ranking of ERFs based on their causal influence and prominence, which accommodates the inherent uncertainty and subjective judgments of experts, is not prominently featured for high-rise projects in Addis Ababa.

d) Limited development of context-specific strategic frameworks for critical ERFs informed by a Fuzzy DEMATEL analysis.

The thesis intends to develop a strategic framework for the most critical ERFs identified through the Fuzzy DEMATEL analysis (addressing Specific Objective 4). Although some sources mention general strategies or remedial measures for risks, the development of a tailored, context-specific framework based on a detailed causal analysis and prioritization of environmental risk factors using Fuzzy DEMATEL, specifically designed for implementation in high-rise building construction projects in Addis Ababa, is not described in the provided literature. This highlights a practical gap in translating the specific findings of such a detailed environmental risk analysis into actionable, strategically-informed management strategies for this particular sector and location.

In summary, this research seeks to provide a nuanced understanding of ERFs in Addis Ababa's high-rise construction sector, focusing on their causal dynamics and prioritized importance, ultimately contributing to the development of more effective and targeted environmental risk management strategies.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter delineates the methodological framework employed to achieve the research aim of conducting a comprehensive causal analysis and prioritization of Environmental Risk Factors (ERFs) affecting high-rise building construction projects in Addis Ababa, and subsequently leveraging these insights to inform the development of a targeted strategic management framework. The specific objectives guiding this research include the identification of key ERFs, the determination of their causal interrelationships and influence levels, their prioritization based on these analyses, and the development of a strategic management framework suitable for implementation in the specified context. This chapter provides an overview of its structure, detailing how each methodological step addresses the research questions and objectives. Furthermore, it offers a justification for the selection of the Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique as the primary analytical tool, emphasizing its suitability for modeling complex causal relationships and accommodating the inherent uncertainties and subjectivities associated with expert judgments in risk assessment.

3.2 Study Area

The geographical and sectoral focus of this research is specifically high-rise building construction projects situated within Addis Ababa, the capital city of Ethiopia. Addis Ababa was selected as the study area due to its rapid urbanization, which has catalyzed a significant increase in construction activities, particularly the development of high-rise buildings. This proliferation of complex construction projects in a concentrated urban environment presents unique and pressing environmental challenges, making it a pertinent context for investigating ERFs and developing tailored management strategies. The findings and the resultant framework are intended to be directly applicable to stakeholders operating within this specific metropolitan construction sector, while also offering insights that may be relevant to other rapidly urbanizing cities in developing countries facing similar environmental management concerns in their construction industries.

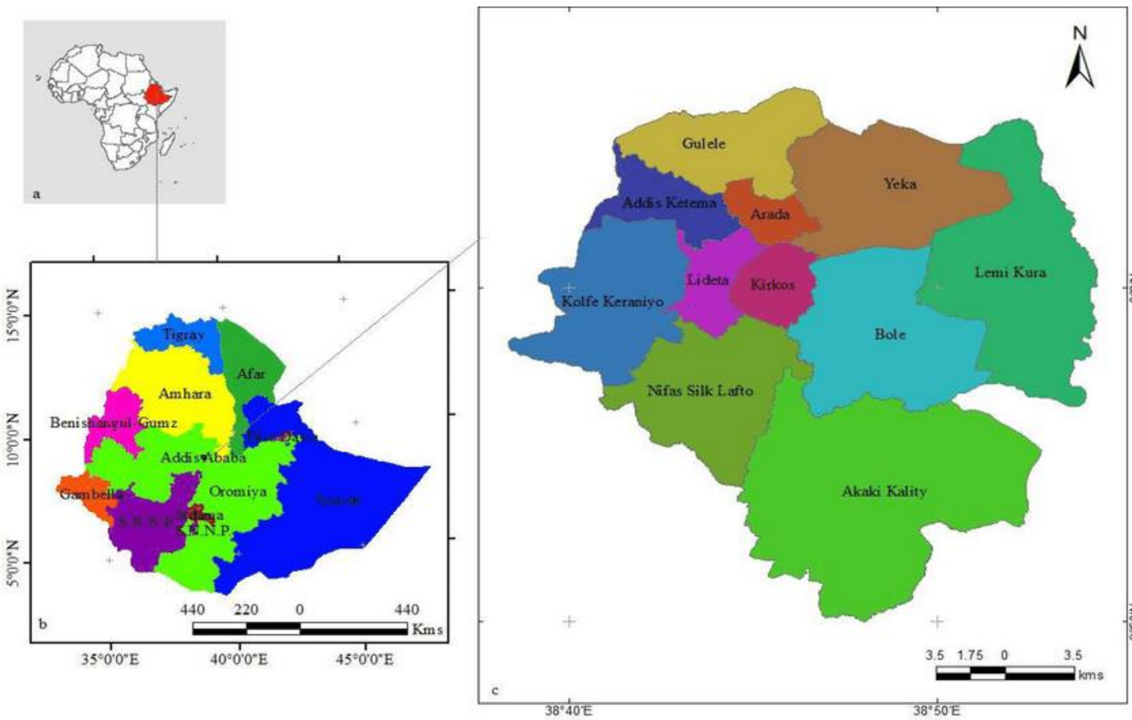


Figure 3.1: Illustrates the location of Addis Ababa within Ethiopia (Moisa *et al.,* 2022).

3.3 Research Design and Approach

This study adopted a pragmatist research philosophy, recognizing the value of integrating both qualitative insights and quantitative analytical techniques to address the multifaceted nature of the research problem. This philosophy underpins the selection of a mixed-methods research design, specifically employing an explanatory and descriptive sequential design to systematically investigate the ERFs in Addis Ababa's high-rise construction sector.

The pragmatist paradigm was deemed most appropriate as it allows for a flexible approach that focuses on the research problem and utilizes diverse methods to achieve practical outcomes. In this study, pragmatism facilitated the combination of qualitative expert input, crucial for identifying contextually relevant ERFs and validating the developed framework, with the quantitative processing capabilities of the Fuzzy DEMATEL technique, essential for analyzing complex causal interdependencies.

The research strategy followed a sequential, multi-phase approach. Phase 1: ERF Identification was primarily qualitative and literature-based, involving an extensive review of academic and industry sources to compile an initial list of potential ERFs. This was followed by initial expert consultations to validate and refine this list for the Addis Ababa context. Phase 2: Fuzzy DEMATEL Application involved the quantitative processing of expert judgments. Data collected from a panel of experts regarding the pairwise influence of the identified ERFs were analyzed using the Fuzzy DEMATEL methodology to determine causal interrelationships, prominence, and relation values. Phase 3: Strategic Framework Development then synthesized the outputs from the Fuzzy DEMATEL analysis with further expert insights and established best practices to construct a targeted management framework for the prioritized ERFs. This sequential design ensured that each phase built logically upon the preceding one, leading to a robust and contextually grounded outcome.

The mixed-methods nature of this study was integral to its success. Qualitative expert consultations played a critical role in the initial ERF identification and refinement, ensuring that the factors subjected to quantitative analysis were indeed pertinent and comprehensively represented the local context. These qualitative insights also provided rich contextual understanding that informed the interpretation of the Fuzzy DEMATEL results. Furthermore, qualitative expert feedback was instrumental in validating the practical applicability and relevance of the strategic management framework developed from the quantitative analysis. This iterative interplay between qualitative contextualization and quantitative analysis enhanced the rigor, validity, and practical utility of the research findings and the final framework.

3.4 Data Collection

The data collection process for this research was systematically structured into two distinct phases, corresponding directly to the sequential nature of the research strategy and designed to address the specific objectives of the study.

3.4.1 Phase 1: Identification of Key Environmental Risk Factors (ERFs) (Addressing Specific Objective 1)

The initial phase of data collection was dedicated to the identification of key Environmental Risk Factors (ERFs) pertinent to high-rise building construction projects in Addis Ababa. This commenced with Secondary Data Collection, which involved a comprehensive literature review. Academic papers, industry reports, prevailing environmental regulations, and construction guidelines were meticulously examined to generate an initial, extensive list of potential ERFs. This review also encompassed previous studies on construction risks, with a particular focus on environmental risks in comparable contexts, such as developing countries and urban high-rise projects, to ensure a broad and informed starting point.

Following the secondary data collection, Primary Data Collection was undertaken in the form of an Initial Expert Consultation. The preliminary list of ERFs derived from the literature was subjected to a process of refinement and validation through consultations with a small, purposively selected group of key experts. These experts, chosen for their profound knowledge and experience in Addis Ababa's high-rise construction sector and/or environmental management, participated in activities such as pilot interviews and structured discussions. The objective of this consultation was to ensure the contextual relevance, clarity, distinctness, and comprehensiveness of the ERF list specifically for Addis Ababa's high-rise sector. The Output of this first phase was a finalized and validated list of ERFs, which subsequently formed the basis for the Fuzzy DEMATEL analysis.

3.4.2 Phase 2: Data for Fuzzy DEMATEL Application (Addressing Specific Objectives 2 & 3)

The second phase of data collection focused on gathering the necessary inputs for the Fuzzy DEMATEL application, which aimed to determine the causal interrelationships and prioritize the identified ERFs. This began with Expert Panel Selection. A panel of thirteen (13) experts was carefully chosen based on predefined criteria, emphasizing significant experience in high-rise construction, environmental management, and demonstrable knowledge of the Addis Ababa construction context, along with relevant professional qualifications. Efforts were made to ensure the Representativeness of the panel, drawing experts from diverse organizational backgrounds including client bodies, consultancy firms, contracting companies, academic institutions, and regulatory agencies, to capture a multifaceted perspective.

Subsequently, Data Collection Instrument Development involved the meticulous design of the Fuzzy DEMATEL questionnaire. This instrument provided clear Instructions for pairwise comparison of ERFs based on their direct influence. It also included a precise Definition of linguistic variables (e.g., No Influence, Low Influence, Medium Influence, High Influence, Very High Influence) and their corresponding triangular fuzzy numbers (TFNs) to be used for scaling the perceived influence, thereby accommodating the vagueness inherent in expert judgments.

The Data Collection Procedure then entailed the administration of this Fuzzy DEMATEL questionnaire to the selected expert panel. Each expert was tasked with independently evaluating the direct influence of each ERF on every other ERF in the validated list. The primary data collected in this phase consisted of these expert judgments on the direct influence between pairs of ERFs, expressed using the predefined linguistic scale. These judgments formed the raw data for the subsequent Fuzzy DEMATEL computational analysis.

3.5 Fuzzy DEMATEL Application and Data Analysis (Addressing Specific Objectives 2 & 3)

Subsequent to the data collection phases, this research employed the Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique to analyze the gathered expert judgments. This methodological application was central to addressing the second and third specific objectives: determining the causal interrelationships and influence levels among the identified Environmental Risk Factors (ERFs), and subsequently prioritizing these ERFs based on the analytical outcomes.

3.5.1 Overview of the Fuzzy DEMATEL Technique

The DEMATEL technique is a well-established structural modeling approach primarily utilized for analyzing causal relationships among complex factors and identifying critical elements within a system. Its core purpose is to construct a visual map that illustrates the contextual relations and the intensity of influence between system components. For this research, the fuzzy variant of DEMATEL was specifically selected.

The justification for employing Fuzzy DEMATEL stems from its inherent capability to effectively handle the vagueness, imprecision, and uncertainty often associated with human linguistic judgments, which are characteristic of expert opinions in risk assessment. By representing expert assessments as fuzzy numbers rather than crisp values, this approach provides a more realistic and nuanced representation of the subjective evaluations regarding the influence of one ERF upon another.

3.5.2 Steps in Fuzzy DEMATEL Analysis

The application of the Fuzzy DEMATEL methodology involved a systematic sequence of ten analytical steps, designed to transform the qualitative expert opinions into a structured understanding of ERF interdependencies and priorities:

The process commenced with Step 1: Defining Linguistic Variables and Fuzzy Scales, which had been established during the data collection instrument development phase (as detailed in Section 3.4.2). This involved assigning specific triangular fuzzy numbers (TFNs) to the linguistic terms used by experts to rate the direct influence between ERFs. Step 2: Collecting Expert Opinions and Constructing Individual Fuzzy Direct-Relation Matrices involved transcribing each expert's linguistic assessments of pairwise ERF influences into individual matrices where each element was a TFN.

In Step 3: Aggregating Expert Opinions to form the Average Fuzzy Direct-Relation Matrix, the individual fuzzy matrices from all participating experts were combined. This was achieved by averaging the corresponding lower, middle, and upper values of the TFNs for each pairwise relationship, resulting in a single aggregated fuzzy direct-relation matrix that represented the collective judgment of the expert panel. Subsequently, Step 4: Normalizing the Average Fuzzy Direct-Relation Matrix was performed. This normalization process, using a scaling factor derived from the matrix, ensured that all fuzzy influence values were transformed into a comparable range, typically between 0 and 1, which is a prerequisite for subsequent matrix operations.

Step 5: Computing the Fuzzy Total-Relation Matrix ($\tilde{T}$) was a crucial stage, as this matrix encapsulates not only the direct influences but also the indirect influences propagated through the network of ERFs. This was calculated using established matrix operations on the normalized fuzzy direct-relation matrix. Following this, Step 6: Calculating Prominence ($\tilde{D}+\tilde{R}$) and Relation ($\tilde{D}-\tilde{R}$) values involved deriving two key fuzzy vectors for each ERF from the fuzzy total-relation matrix. The fuzzy vector $\tilde{D}$, obtained by summing the rows of $\tilde{T}$, represented the total influence an ERF dispatches to others, while the fuzzy vector $\tilde{R}$, obtained by summing the columns of $\tilde{T}$, represented the total influence an ERF receives from others. The sum ($\tilde{D}+\tilde{R}$) provided the fuzzy prominence (overall importance) of each ERF, and the difference ($\tilde{D}-\tilde{R}$) indicated its fuzzy net causal effect (relation).

To facilitate clearer interpretation and ranking, Step 7: Defuzzification of Prominence and Relation values was undertaken. The fuzzy ($\tilde{D}+\tilde{R}$) and ($\tilde{D}-\tilde{R}$) values were converted into crisp numerical scores, for which the Centroid method was employed in this study due to its robustness in representing the central tendency of a fuzzy number. These crisp values then enabled Step 8: Prioritization of ERFs based on defuzzified Prominence (D+R) values, allowing for a hierarchical ranking of ERFs according to their overall systemic influence. Step 9: Categorization of ERFs into cause and effect groups based on Relation (D-R) values involved classifying ERFs as net dispatchers (causes) if their (D-R) value was positive, or as net receivers (effects) if negative, with the magnitude indicating the strength of this causal role.

Finally, Step 10: Construction of the Causal Diagram (Influence Relation Map - IRM) involved plotting each ERF on a two-dimensional graph, with the defuzzified prominence (D+R) values on the x-axis and the defuzzified relation (D-R) values on the y-axis. This IRM provided a visual representation of the complex interrelationships among the ERFs, clearly distinguishing influential dispatchers from highly impacted receivers and illustrating the overall structure of the environmental risk system in Addis Ababa's high-rise construction projects.

3.6 Development of a Strategic Framework (Addressing Specific Objective 4)

The culmination of the analytical phases of this research was the development of a strategic framework specifically designed to manage the critical Environmental Risk Factors (ERFs) identified and prioritized for high-rise building construction projects in Addis Ababa. This phase directly addressed the fourth specific objective of the study, translating the empirical findings from the Fuzzy DEMATEL analysis into a structured, actionable approach for environmental risk management.

The initial step in constructing this framework, 3.6.1 Synthesizing Fuzzy DEMATEL Results, involved a meticulous interpretation of the outputs from the causal analysis. This entailed identifying the ERFs exhibiting the highest prominence (D+R values), indicating their overall systemic importance, as well as those demonstrating significant net causal effects (D-R values). A clear understanding of the derived causal structure, which delineated key influential 'dispatcher' (cause) ERFs and significantly 'influenced' (receiver) ERFs, was paramount. This synthesis formed the evidence-based foundation upon which targeted management interventions could be built.

Subsequently, 3.6.2 Incorporating Qualitative Insights involved integrating the quantitative findings with qualitative understanding. Where applicable and as planned within the research design, insights gathered from the initial expert consultations (Phase 1 of data collection) and any follow-up discussions were utilized to contextualize the DEMATEL results. This step ensured that the practical nuances, local conditions, and experiential knowledge of experts informed the formulation of practical and contextually relevant management strategies, moving beyond purely numerical interpretations.

The design of the framework was then guided by 3.6.3 Framework Design Principles. These principles, derived from the nature of the identified ERFs and established best practices in risk management, included a primary focus on proactive and preventative measures specifically for the identified dispatcher ERFs, recognizing their role as root drivers of other environmental issues. Concurrently, the framework emphasized the development of robust reactive and mitigation measures for the receiver ERFs, which, while being outcomes, often have significant direct impacts. A crucial design principle was the explicit consideration of stakeholder roles and responsibilities in managing the prioritized ERFs, acknowledging that effective environmental risk management is a collaborative endeavor. Furthermore, the framework was built upon foundational tenets such as regulatory compliance, local context awareness, stakeholder collaboration, commitment to sustainable construction, and continuous improvement, as detailed in Section 4.6.2.

Finally, 3.6.4 Validation of the Framework was undertaken to ensure its practical utility and relevance. Although optional in some research designs, this step was deemed highly recommended and was conducted by presenting the draft strategic framework to a subset of experts. These experts, possessing significant experience in Addis Ababa's construction sector, provided critical feedback on the clarity, comprehensiveness, practicality, and contextual appropriateness of the proposed strategies and overall structure. This iterative feedback and refinement process, as detailed in Section 4.6.4, aimed to enhance the framework's implementability and ensure its alignment with the operational realities of high-rise construction projects in Addis Ababa, ultimately confirming its soundness and potential efficacy.

3.7 Data Analysis Software

The execution of the data analysis procedures delineated in this research was facilitated by the application of specialized software tools, selected for their specific capabilities in managing and processing the diverse data types generated.

For the management and initial thematic analysis of qualitative data derived from the initial expert consultations (Phase 1 of data collection), where expert feedback on the relevance, clarity, and significance of Environmental Risk Factors (ERFs) was gathered, a standard spreadsheet program such as Microsoft Excel was employed. This allowed for the systematic tabulation of expert responses, calculation of mean scores for relevance and significance, and organization of qualitative comments pertaining to ERF modification, merging, or removal.

The core quantitative analysis, specifically the complex computations required for the Fuzzy DEMATEL methodology (addressing Specific Objectives 2 & 3), was conducted using the Python programming language within the Google Colaboratory (Colab) environment. Python, with its extensive libraries for numerical computation (e.g., NumPy for matrix operations) and data manipulation (e.g., Pandas for handling datasets), provided the necessary flexibility and power to implement the multi-step Fuzzy DEMATEL algorithm. This included the construction of individual and aggregated fuzzy direct-relation matrices, normalization procedures, computation of the fuzzy total-relation matrix, and the subsequent calculation of fuzzy prominence ($\tilde{D}+\tilde{R}$) and relation ($\tilde{D}-\tilde{R}$) vectors. The Google Colab platform facilitated a reproducible and well-documented analytical workflow.

For the visualization of results, particularly the construction of the Causal Diagram (Influence Relation Map - IRM) and other graphical representations of ERF prominence and relation values, Python's data visualization libraries, such as Matplotlib and Seaborn, were utilized. These tools enabled the generation of clear and informative diagrams that effectively communicated the complex interrelationships and prioritizations emerging from the Fuzzy DEMATEL analysis, thereby aiding in the interpretation and synthesis of findings. Microsoft Excel was also utilized for generating basic charts and tables for descriptive statistics related to the expert panel and ERF validation. The selection of these software tools was based on their widespread availability, robust analytical capabilities, and suitability for the specific data processing and visualization requirements of this research.

3.8 Reliability and Validity of the Study

Ensuring the trustworthiness and rigor of the research findings necessitated careful attention to aspects of reliability and validity throughout the methodological process. Specific measures were implemented to bolster both the consistency of the data derived from expert judgments and the extent to which the study accurately measured and addressed its intended constructs.

3.8.1 Reliability of Expert Judgments

The reliability of the expert judgments, which form the cornerstone of the Fuzzy DEMATEL analysis, was addressed through several key strategies. Firstly, considerable effort was invested in ensuring the clarity of the questionnaire and data collection instruments. Both the initial ERF validation guide and the subsequent Fuzzy DEMATEL pairwise comparison instrument were designed with unambiguous instructions and precise definitions of linguistic variables and scales. Pilot testing, as mentioned in the implementation notes for the consultation guides, was conducted with a small group of academics and practitioners to refine the instruments and minimize potential for misinterpretation by the main expert panel. Secondly, the selection of knowledgeable and experienced experts was a critical step. As detailed in Section 4.2, experts were chosen based on stringent criteria relating to their years of experience in high-rise construction, environmental management, and specific familiarity with the Addis Ababa context, thereby enhancing the likelihood of informed and consistent responses. While the Fuzzy DEMATEL technique, as applied in this study, typically involves a single round of expert input for pairwise comparisons, it is acknowledged that some MCDM approaches, like Delphi, utilize multiple rounds to achieve consensus and enhance inter-rater reliability. However, the aggregation of judgments from a carefully selected panel of thirteen diverse experts in the Fuzzy DEMATEL process itself contributes to a more stable and reliable collective assessment than individual opinions alone.

3.8.2 Validity

The validity of the research was systematically addressed through multiple dimensions. Content Validity, which refers to the extent to which the measurement instrument covers all relevant aspects of the construct being measured, was established by grounding the initial list of Environmental Risk Factors (ERFs) in a comprehensive review of existing academic literature and industry reports. This initial list was then subjected to rigorous validation and refinement by a panel of local experts (as detailed in Section 4.3), ensuring that the ERFs included were indeed pertinent and comprehensive for the high-rise construction sector in Addis Ababa.

Construct Validity, concerned with whether the study measures the intended theoretical constructs, was primarily ensured by using the established Fuzzy DEMATEL methodology. This technique is well-recognized in academic literature for its ability to model and analyze complex causal interrelationships and hierarchical structures among a set of factors, which aligns directly with the research objectives concerning ERF influence and prioritization. The systematic, step-by-step application of this established methodology (detailed in Section 3.5.2) supports the claim that the study accurately assessed the intended causal constructs.

Expert Panel Validity was addressed by ensuring that the panel of thirteen experts possessed the necessary and demonstrable expertise in high-rise construction, environmental management, and the specific operational context of Addis Ababa. The detailed demographic and professional characteristics of the expert panel, presented in Section 4.2, affirm their qualifications and suitability to provide credible judgments on the ERFs under investigation, thereby validating the data upon which the study's conclusions are based.

Finally, Face Validity, which pertains to the apparent suitability and relevance of the assessment instruments and the overall research approach, was considered. The Fuzzy DEMATEL instrument, along with the preliminary ERF list and the subsequently developed strategic framework, were implicitly reviewed by the participating experts during the data collection and validation phases. Their engagement and constructive feedback throughout these processes suggest that the instruments and the framework were perceived as appropriate and relevant to the research aims and the practical context of environmental risk management. Furthermore, the overall research design and methodology were developed based on established scientific research principles, lending further credence to its face validity.

3.9 Ethical Considerations

This research adhered strictly to established ethical principles, ensuring the protection and respect of all participants. Informed consent was obtained from all experts, outlining the study's objectives, voluntary participation, and the right to withdraw. Confidentiality and anonymity were rigorously maintained by separating identities from judgments and anonymizing data during analysis, enabling candid feedback without professional repercussions. Data was stored securely on password-protected devices and in secure physical locations to prevent unauthorized access and maintain integrity. The study was designed to avoid exposing participants to any harm, focusing solely on professional expertise and fostering a respectful engagement. All ethical guidelines stipulated by

Adama Science and Technology University were strictly followed throughout the research lifecycle.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the empirical findings derived from the systematic application of the research methodology detailed in Chapter Three. Its primary purpose is to address the general objective of this study, which is to conduct a comprehensive causal analysis and prioritization of Environmental Risk Factors (ERFs) affecting high-rise building construction projects in Addis Ababa using the Fuzzy DEMATEL methodology, and to subsequently leverage these insights for the development of a targeted strategic management framework. This chapter will specifically address the research objectives by presenting the results pertaining to the identification of key ERFs, the outcomes of the Fuzzy DEMATEL analysis which elucidate causal interrelationships and influence levels, the subsequent prioritization of these ERFs, and the developed strategic framework designed for their effective management.

The structure of this chapter is organized to guide the reader logically through the presentation of results and their ensuing discussion. It commences with a detailed profile of the expert panel whose judgments formed a crucial input for the analyses. This is followed by the presentation of the validated list of ERFs identified for Addis Ababa's high-rise construction sector. Subsequently, the chapter delves into the core findings of the Fuzzy DEMATEL analysis, including the aggregated direct-relation, normalized direct-relation, and total-relation matrices, as well as the calculated prominence and relation values for each ERF, culminating in the causal diagram. The prioritization of ERFs based on these analytical outputs is then presented. Following this, the chapter details the strategic management framework developed based on these findings. Each section of results is accompanied by a discussion that interprets the findings, relates them back to the specific research objectives, and synthesizes them with existing literature where appropriate. The data sources underpinning these results include the comprehensive literature review, insights from initial expert consultations, and the pairwise comparison data collected from the expert panel via the Fuzzy DEMATEL survey.

4.2 Respondent Profile / Expert Panel Characteristics

This section provides a detailed overview of the demographic and professional characteristics of the expert panel whose judgments formed the cornerstone of the Fuzzy DEMATEL analysis. Understanding the composition of the expert panel is crucial for establishing the credibility and contextual relevance of the study's findings regarding environmental risk factors in high-rise building construction projects in Addis Ababa. The selection of experts was guided by the need to gather insights from individuals with substantial experience and knowledge in the construction industry, particularly concerning high-rise buildings and environmental management.

The Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology, central to this research, intrinsically relies on the subjective judgments and experiential knowledge of a carefully selected panel of experts. The credibility, robustness, and practical applicability of the findings stemming from such an approach are, therefore, directly contingent upon the expertise, experience, and diversity of the participating experts. This section provides a detailed overview of the demographic and professional characteristics of the expert panel whose collective input formed the basis for identifying, analyzing, and prioritizing Environmental Risk Factors (ERFs) in high-rise building construction projects in Addis Ababa. A thorough understanding of the panel's composition is essential for contextualizing the research outcomes and asserting their validity.

4.2.1 Number of Experts

A total of thirteen (13) experts participated in this study. This panel size is consistent with typical requirements for DEMATEL studies, which often involve a focused group of knowledgeable individuals to ensure depth and quality of input rather than sheer numbers. All 13 experts completed the survey instruments, providing the necessary data for the subsequent analytical phases.

4.2.2 Professional Background/Current Role

The professional roles of the participating experts were varied, ensuring a multifaceted perspective on environmental risk factors in high-rise construction. The distribution of these roles is crucial for capturing insights from different operational standpoints within the industry. Table 4.1 summarizes the primary professional roles of the expert panel.

Table 4.1: Distribution of Experts by Professional Role

Professional Role	**Frequency**	**Percentage (%)**
Consultant (e.g., Design, Engineering, Project Management, Environmental)	6	46.15
Environmental Specialist / Scientist	2	15.38
Academic / Researcher	2	15.38
Government Agency Representative / Regulator	2	15.38
Contractor / Construction Manager	1	7.69
Total	**13**	**100.00**

As indicated in Table 4.1, the largest group of experts (46.15%) comprised consultants involved in various aspects of project design, engineering, project management, and environmental assessment. This was complemented by representation from Environmental Specialists/Scientists, Academics/Researchers, and Government Agency Representatives/Regulators, each constituting 15.38% of the panel. A practicing Contractor/Construction Manager also contributed, ensuring that practical site-level perspectives were included. This blend of roles suggests that the collected data benefits from a balanced mix of theoretical knowledge, regulatory understanding, design considerations, and practical implementation experience concerning high-rise construction and environmental management in Addis Ababa.

4.2.3 Organizational Affiliation

The organizational affiliations of the experts provide further insight into the breadth of perspectives incorporated into the study. Experts were drawn from a range of organizations, including private sector firms, academic institutions, and governmental bodies. Table 4.2 presents the distribution of experts based on their primary type of organization.

Table 4.2: Distribution of Experts by Organizational Affiliation

Type of Organization	**Frequency**	**Percentage (%)**
Private Consultancy Firm	6	46.15
Academic Institution	4	30.77
Private Construction Company (Contractor)	1	7.69
Government Ministry / Agency	1	7.69
Other (Not Specified)	1	7.69
Total	**13**	**100.00**
(Note: One expert's role as a Government Agency Representative was affiliated with a Private Consultancy Firm in the provided data; reported as per source data.)		

The data in Table 4.2 shows that a significant portion of the experts (46.15%) were affiliated with Private Consultancy Firms, followed by Academic Institutions (30.77%). Representation from a Private Construction Company and a Government Ministry/Agency, each at 7.69%, further diversifies the panel. This distribution indicates a strong presence of professionals actively engaged in project execution and advisory services, as well as those involved in research and education related to the construction industry. The inclusion of experts from governmental bodies also brings a regulatory and policy perspective to the study.

4.2.4 Years of Experience

The experience level of the expert panel is a critical determinant of the quality and depth of insights obtained. The panel's experience was assessed in three key areas: overall experience in the construction industry, specific experience with high-rise building projects (defined as 15-45 stories according to FDRE Directive 649/2021), and experience dealing with environmental aspects or risks in construction projects. Table 4.3 provides a summary of the experts' years of experience across these domains.

Table 4.3: Summary of Experts' Years of Experience (N=13)

Experience Category	**Minimum (Years)**	**Maximum (Years)**	**Mean (Years)**
Total Experience in the Construction Industry	11	35	22.69
Experience with High-Rise Building Projects	3	27	12.15
Experience with Environmental Aspects/Risks in Construction	0	27	5.46

The experts possessed substantial experience in the construction industry, with an average of 22.69 years, ranging from 11 to 35 years. This indicates a mature panel with long-term engagement in the sector.

Specifically concerning high-rise building projects, the average experience was 12.15 years, with a range from 3 to 27 years, demonstrating considerable familiarity with the complexities of such structures. Regarding experience with environmental aspects and risks in construction, the average was 5.46 years. While four experts reported no direct specialized experience in this specific niche, their extensive overall construction and high-rise experience still provides valuable contextual understanding. The remaining nine experts had direct experience ranging from 1 to 27 years in environmental management or risk assessment within construction. The collective experience profile suggests that the panel was well-equipped to provide informed judgments on the environmental risks pertinent to high-rise construction in Addis Ababa.

4.2.5 Educational Qualifications

The educational background of the expert panel underscores their technical and theoretical knowledge base. The majority of the experts held postgraduate degrees, reflecting a high level of formal education in fields relevant to construction engineering and management. Table 4.4 details the highest educational qualifications attained by the experts.

Table 4.4: Distribution of Experts by Highest Educational Qualification

Highest Educational Qualification	**Frequency**	**Percentage (%)**
Master's Degree (MSc, MA, M.Eng, MBA, etc.)	7	53.85
Doctoral Degree (PhD, D.Eng, etc.)	5	38.46
Professional Certification (PEng Civil/Structural)	1	7.69
Total	**13**	**100.00**

As shown in Table 4.4, over half of the experts (53.85%) held Master's degrees, and a significant proportion (38.46%) possessed Doctoral degrees. One expert's highest listed qualification was a professional certification. This high level of academic achievement, combined with their extensive professional experience, indicates that the panel possessed a strong foundation of both theoretical knowledge and practical expertise, further enhancing the reliability of their input for the study.

4.2.6 Familiarity with Risk Management and High-Rise Construction in Addis Ababa

In summary, the expert panel assembled for this study exhibited a robust profile well-suited to address the research objectives. The 13 experts collectively brought a wealth of experience, averaging over two decades in the construction industry and over a decade specifically with high-rise projects. Their professional roles spanned consultancy, environmental science, academia, regulation, and contracting, ensuring a diverse range of perspectives. Furthermore, the majority of the panel held postgraduate qualifications (Master's or Doctoral degrees), signifying a strong theoretical and analytical grounding. The combination of extensive practical experience, diverse organizational affiliations, and high educational attainment indicates that the panel was highly familiar with the nuances of risk management, the specific challenges of high-rise construction, and the environmental context of Addis Ababa. This comprehensive expertise is fundamental to the validity and contextual relevance of the ERFs identified and subsequently analyzed using the Fuzzy DEMATEL approach in this thesis.

4.3 Identification of Key Environmental Risk Factors (ERFs) (Addressing Specific Objective 1)

This section details the systematic process undertaken to identify and refine the key Environmental Risk Factors (ERFs) pertinent to high-rise building construction projects in Addis Ababa, Ethiopia. The identification of these ERFs is foundational to this research and directly addresses the first specific objective: to identify the key ERFs pertinent to high-rise building construction projects in Addis Ababa through a comprehensive literature review and expert consultations. The outcome of this phase is a validated list of ERFs that forms the basis for the subsequent Fuzzy DEMATEL analysis.

4.3.1 Initial ERF Identification from Literature

The initial step in identifying potential ERFs involved a comprehensive review of existing academic literature, industry reports, environmental regulations, and construction guidelines, as presented in Chapter Two of this thesis. This literature survey aimed to gather a broad spectrum of environmental risks that have been recognized in construction projects globally, with a particular focus on studies related to developing countries and, where available, high-rise building contexts. The process involved examining common risk categories, their documented impacts, and specific challenges associated with construction activities.

The synthesis of this review led to an initial, extensive list of potential ERFs. These factors were systematically categorized to provide structure and understanding, encompassing areas such as general environmental and regulatory risks, natural phenomena and weather-related risks, site-specific environmental and physical risks, environmental impacts directly resulting from construction activities and resource use, and risks associated with the adoption of sustainable or green construction practices. A detailed compilation of these initially identified ERFs, along with their sources, was presented in Table 2.1 of the Literature Review chapter. This table served as the preliminary inventory of ERFs that were subjected to further validation and refinement through expert consultation to ensure their contextual relevance to high-rise building projects in Addis Ababa.

4.3.2 ERF Validation and Refinement through Initial Expert Consultation

Following the initial identification of ERFs from the literature, an expert consultation process was conducted to validate, refine, and contextualize this list specifically for high-rise building construction projects in Addis Ababa. This step was crucial to ensure that the ERFs carried forward for analysis were indeed pertinent and significant within the local construction environment. A structured consultation guide (as detailed in the 'Expert Consultations' document) was distributed to a panel of experts with significant experience and knowledge in the Ethiopian construction sector, particularly concerning high-rise buildings and/or environmental management. These experts represented diverse backgrounds, including contractors, consultants, academics, and regulatory bodies, to provide a holistic perspective.

Experts were asked to evaluate each ERF from the preliminary list based on several criteria:

- Relevance: How relevant the ERF is to high-rise building construction projects in Addis Ababa.
- Significance: The potential level of impact of the ERF if not properly managed.
- Clarity & Distinctness: The clarity of the ERF's wording and whether it was a distinct factor or overlapped significantly with others.

- Recommendation: Whether the ERF should be kept, kept with modification, removed, or merged with other ERFs.

The responses, as summarized in the 'expert_consultation_summary_responses.csv' data, indicated varying degrees of relevance and significance for the initial list of ERFs. For example, factors like "Environmental Protection Pressure" (originally 1.2) and "Earthquake / Seismic Activity" (originally 2.12) received high mean relevance and significance scores and strong recommendations to be kept. Conversely, some ERFs that were broader or perceived as less impactful in the Addis Ababa high-rise context, such as "Environmental Risk / Concerns (as a broad category)" (originally 1.1) or "Wind (including strong winds at height for high-rise)" (originally 2.7) when considered less critical than other specific weather phenomena, were often recommended for merging or removal, supported by justifications about overlap or lower perceived impact.

The qualitative feedback was instrumental in this refinement process. Experts provided specific suggestions for rewording ERFs to enhance clarity (e.g., making "Flood (urban flooding, site-specific)" more precise), identified overlaps leading to mergers (e.g., merging some general weather condition ERFs), and proposed new ERFs deemed critical for the local context but not adequately covered in the initial list. For instance, experts proposed "Weak enforcement of existing environmental regulations" and "Inadequate consideration of urban heat island effect in design" as important additions. This iterative process of quantitative rating and qualitative feedback allowed for a systematic reduction and refinement of the initial list, ensuring that the selected ERFs were comprehensive, distinct, and highly relevant to the specific focus of the study.

4.3.3 Final List of ERFs for Fuzzy DEMATEL Analysis

Based on the comprehensive literature review and the subsequent rigorous validation and refinement process involving expert consultations, a final list of key Environmental Risk Factors (ERFs) pertinent to high-rise building construction projects in Addis Ababa was established. This list represents a consensus from expert judgment, prioritizing factors deemed most relevant and significant for the local context, while also ensuring clarity and distinctiveness among the ERFs. These factors were then carried forward for the Fuzzy DEMATEL analysis.

Table 4.1 presents the final validated list of ERFs, including their refined descriptions, original reference numbers from the initial list (where applicable), their categories, and a summary of the expert panel's assessment that justified their inclusion. The mean relevance and significance scores derived from the expert survey (rated on a scale of 0-3, where 3 is highest) are also provided to illustrate the perceived importance of each ERF. Newly proposed ERFs that achieved consensus for inclusion are also listed.

Table 4.5: Final List of ERFs for High-Rise Building Construction Projects in Addis Ababa.......58

Final ERF No.	**Refined ERF Description**	**Category**	**Original ERF No. / Proposed**	**Mean Relevance (0-3)**	**Mean Significance (0-3)**	**Justification for Inclusion based on Expert Consultation**
ERF1	Environmental Protection Pressure	Environmental Risks (General & Regulatory)	1.2	1.92	2.15	High expert consensus (Rel: 1.92, Sig: 2.15). Recommended Keep/Modify by 7 experts.
ERF2	Natural Phenomena / Extreme Weather / Force Majeure Events (general)	Natural Phenomena / Weather Risks	2.1	1.85	2.00	High expert consensus (Rel: 1.85, Sig: 2.0). Recommended Keep/Modify by 9 experts.
ERF3	Storms (wind, dust storms relevant to Addis)	Natural Phenomena / Weather Risks	2.4	1.92	1.85	High expert consensus (Rel: 1.92, Sig: 1.85). Recommended Keep/Modify by 9 experts.
ERF4	Humidity Extremes/Variations	Natural Phenomena / Weather Risks	2.6	2.00	2.38	High expert consensus (Rel: 2.0, Sig: 2.38). Recommended Keep/Modify by 12 experts.
ERF5	Flood (urban flooding, site-specific)	Natural Phenomena / Weather Risks	2.9	2.23	2.23	High expert consensus (Rel: 2.23, Sig: 2.23). Recommended Keep/Modify by 9 experts.

ERF6	Landslip / Landslide (site stability, excavation related)	Natural Phenomena / Weather Risks	2.11	2.38	2.46	High expert consensus (Rel: 2.38, Sig: 2.46). Recommended Keep/Modify by 10 experts.
ERF7	Earthquake / Seismic Activity	Natural Phenomena / Weather Risks	2.12	2.46	2.38	High expert consensus (Rel: 2.46, Sig: 2.38). Recommended Keep/Modify by 10 experts.
ERF8	Unforeseen / Differing Site Conditions (DSC) (geotechnical, groundwater)	Site-Specific Environmental & Physical Risks	3.1	2.23	2.46	High expert consensus (Rel: 2.23, Sig: 2.46). Recommended Keep/Modify by 9 experts.
ERF9	Adverse Geological Conditions (site-related, e.g., expansive soils)	Site-Specific Environmental & Physical Risks	3.2	2.62	2.77	High expert consensus (Rel: 2.62, Sig: 2.77). Recommended Keep/Modify by 10 experts.
ERF10	Site Contamination / Pollution-related Conditions (pre-existing)	Site-Specific Environmental & Physical Risks	3.3	2.00	2.15	High expert consensus (Rel: 2.0, Sig: 2.15). Recommended Keep/Modify by 9 experts.
ERF11	Difficulty Accessing Site (due to environmental/site conditions, e.g., narrow urban, topography)	Site-Specific Environmental & Physical Risks	3.4	2.08	2.00	High expert consensus (Rel: 2.08, Sig: 2.0). Recommended Keep/Modify by 8 experts.
ERF12	Pollution from Construction Activities (general, incl. discharge of chemicals/materials)	Environmental Impacts & Resource-Related Risks	4.1	2.54	2.77	High expert consensus (Rel: 2.54, Sig: 2.77). Recommended Keep/Modify by 11 experts.

ERF13	Air Pollution (dust, emissions from equipment/vehicles)	Environmental Impacts & Resource-Related Risks	4.2	2.31	2.54	High expert consensus (Rel: 2.31, Sig: 2.54). Recommended Keep/Modify by 10 experts.
ERF14	Water Pollution (surface runoff, groundwater contamination)	Environmental Impacts & Resource-Related Risks	4.3	2.69	2.38	High expert consensus (Rel: 2.69, Sig: 2.38). Recommended Keep/Modify by 12 experts.
ERF15	Land Pollution (spills, improper waste disposal on/off-site)	Environmental Impacts & Resource-Related Risks	4.4	2.00	2.23	High expert consensus (Rel: 2.0, Sig: 2.23). Recommended Keep/Modify by 10 experts.
ERF16	Noise Pollution (impact on surrounding areas)	Environmental Impacts & Resource-Related Risks	4.5	2.08	2.23	High expert consensus (Rel: 2.08, Sig: 2.23). Recommended Keep/Modify by 8 experts.
ERF17	Increased Resource / Raw Material Consumption (inefficient use)	Environmental Impacts & Resource-Related Risks	4.7	2.15	2.15	High expert consensus (Rel: 2.15, Sig: 2.15). Recommended Keep/Modify by 7 experts.
ERF18	Increased Water Consumption (for construction processes)	Environmental Impacts & Resource-Related Risks	4.8	2.38	2.08	High expert consensus (Rel: 2.38, Sig: 2.08). Recommended Keep/Modify by 10 experts.
ERF19	Waste Generation, Management & Disposal Issues (C&D waste)	Environmental Impacts & Resource-Related Risks	4.9	2.46	2.38	High expert consensus (Rel: 2.46, Sig: 2.38). Recommended Keep/Modify by 9 experts.

ERF20	Public Health and Safety Risks (from waste, pollution, hazardous materials)	Environmental Impacts & Resource-Related Risks	4.12	2.77	2.54	High expert consensus (Rel: 2.77, Sig: 2.54). Recommended Keep/Modify by 13 experts.
ERF21	Challenges with Green/Eco-friendly Materials & Equipment (availability, performance)	Risks Related to Sustainable/Green Practices	5.1	2.00	2.15	High expert consensus (Rel: 2.0, Sig: 2.15). Recommended Keep/Modify by 9 experts.
ERF22	Weak enforcement of existing environmental regulations	General Environmental / Cross-cutting	Prop2	N/A (New)	N/A (New)	Proposed by 2 experts as critical for Addis Ababa. (Regulations exist but follow-through is often lacking on sites.)
ERF23	Inadequate consideration of urban heat island effect in design	General Environmental / Cross-cutting	Prop4	N/A (New)	N/A (New)	Proposed by 2 experts as critical for Addis Ababa. (High-rise density can exacerbate UHI, not always in local design codes.)

The final list comprises 23 ERFs, which were deemed by the expert panel to be the most critical for high-rise building construction projects in Addis Ababa. This refined set of ERFs effectively balances comprehensiveness with manageability for the subsequent complex analytical techniques. The process of literature review combined with targeted expert consultation ensured that the identified ERFs are not only academically grounded but also practically relevant to the unique challenges and conditions of the Addis Ababa construction sector, thereby fulfilling the first specific objective of this research. This validated list provides a solid foundation for analyzing causal interrelationships and prioritizing these ERFs in the following stages of the study.

4.4 Fuzzy DEMATEL Analysis of ERFs (Addressing Specific Objective 2)

Following the identification and validation of the 23 key Environmental Risk Factors (ERFs) pertinent to high-rise building construction projects in Addis Ababa, as detailed in Section 4.3, the next phase of the research involved applying the Fuzzy DEMATEL (Decision-Making Trial and Evaluation Laboratory) technique. This addresses the second specific objective of the study: *To determine the causal interrelationships and influence levels (prominence and relation) among the identified ERFs using the Fuzzy DEMATEL technique, with input from construction industry and environmental experts in Addis Ababa.* The Fuzzy DEMATEL method was selected for its capability to model and analyze complex causal relationships among factors while accommodating the inherent vagueness and subjectivity often present in expert judgments. This section outlines the steps and presents the results of this analysis.

4.4.1 Aggregated Fuzzy Direct-Relation Matrix ($\tilde{A}$)

The Fuzzy DEMATEL process commenced with collecting pairwise comparison judgments from the 13 experts. For each pair of ERFs (ERF_i, ERF_j), experts were asked to assess the direct influence of ERF_i on ERF_j using a five-level linguistic scale: No Influence (N), Low Influence (L), Medium Influence (M), High Influence (H), and Very High Influence (VH). These linguistic assessments were then converted into Triangular Fuzzy Numbers (TFNs) as defined in the methodology (Section 3.5.2 and Consultation Guide - Phase 2, Section 2.B): N (0.0, 0.0, 0.25), L (0.0, 0.25, 0.50), M (0.25, 0.50, 0.75), H (0.50, 0.75, 1.00), and VH (0.75, 1.00, 1.00). Diagonal elements, representing the influence of an ERF on itself, were considered 'No Influence' (N).

The individual fuzzy direct-relation matrices from each of the 13 experts were then aggregated to form a single average fuzzy direct-relation matrix, denoted as $\tilde{A}$. This aggregation was performed by averaging the lower, middle, and upper values of the TFNs provided by all experts for each corresponding cell (i, j) in the matrix. The resulting $\tilde{A}$ matrix, a 23x23 matrix, represents the collective expert judgment on the direct influences among the ERFs. Due to its size, the full $\tilde{A}$ matrix is presented in Appendix B. Each element $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ in this matrix is a TFN representing the aggregated fuzzy direct influence of ERF_i on ERF_j.

4.5 Normalized Fuzzy Direct-Relation Matrix ($\tilde{X}$)

The next step in the Fuzzy DEMATEL process involved normalizing the aggregated average fuzzy direct-relation matrix $\tilde{A}$ to obtain the normalized fuzzy direct-relation matrix, $\tilde{X}$. Normalization ensures that the fuzzy numbers fall within a comparable scale and is a prerequisite for calculating the total-relation matrix. This was achieved by first calculating a scaling factor, *r*, based on the maximum sum of the upper bounds of the TFNs in any row of $\tilde{A}$. Each TFN element (l_{ij}, m_{ij}, u_{ij}) in $\tilde{A}$ was then divided by *r* to obtain the corresponding normalized TFN element $(l'_{ij}, m'_{ij}, u'_{ij})$ in $\tilde{X}$, where $l'_{ij} = l_{ij}/r$, $m'_{ij} = m_{ij}/r$, and $u'_{ij} = u_{ij}/r$.

The resulting normalized fuzzy direct-relation matrix $\tilde{X}$, also a 23x23 matrix, contains TFNs where the values are typically between 0 and 1. This matrix, like $\tilde{A}$, is extensive and is detailed in Appendix C.

4.5.1 Fuzzy Total-Relation Matrix ($\tilde{T}$)

The fuzzy total-relation matrix, $\tilde{T}$, was then computed from the normalized fuzzy direct-relation matrix $\tilde{X}$. The $\tilde{T}$ matrix is significant because it encapsulates not only the direct influences (as in $\tilde{A}$ and $\tilde{X}$) but also the indirect influences among the ERFs. This is calculated using the formula $\tilde{T} = \tilde{X}(I - \tilde{X})^{-1}$, where I is the identity matrix. The computation involves matrix operations on the TFNs, considering their lower, middle, and upper bounds separately.

The elements $\tilde{t}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$ of the $\tilde{T}$ matrix represent the total fuzzy influence (direct and indirect) that ERF_i has on ERF_j. This matrix is crucial for understanding the overall interconnectedness and systemic impact within the network of ERFs. The full 23x23 fuzzy total-relation matrix $\tilde{T}$ is provided in Appendix D.

The analysis of the fuzzy total-relation matrix $\tilde{T}$, particularly its crisp counterpart, reveals the intricate web of influences among the environmental risk factors. For instance, examining the top influences in Table 4.3 (Appendix F) highlights which ERFs exert the most substantial overall impact on others, considering both direct and cascading effects.

4.5.2 Calculation of Fuzzy Prominence ($\tilde{D}+\tilde{R}$) and Relation ($\tilde{D}-\tilde{R}$) Vectors

From the fuzzy total-relation matrix $\tilde{T}$, two important fuzzy vectors, $\tilde{D}$ and $\tilde{R}$, were calculated for each ERF. For each ERF_i, $\tilde{D}_i$ is the sum of the TFNs in the *i*-th row of $\tilde{T}$ (i.e., $\tilde{D}_i = \sum_j \tilde{t}_{ij}$), representing the total fuzzy influence that ERF_i dispatches to all other ERFs. Similarly, $\tilde{R}_i$ is the sum of the TFNs in the *i*-th column of $\tilde{T}$ (i.e., $\tilde{R}_i = \sum_j \tilde{t}_{ji}$), representing the total fuzzy influence that ERF_i receives from all other ERFs.

Using these $\tilde{D}$ and $\tilde{R}$ vectors, the fuzzy prominence vector ($\tilde{D}+\tilde{R}$) and the fuzzy relation vector ($\tilde{D}-\tilde{R}$) were computed for each ERF.

- The **fuzzy prominence ($\tilde{D}_i+\tilde{R}_i$)** indicates the overall importance or total influential involvement of ERF_i within the system. A higher ($\tilde{D}+\tilde{R}$) value signifies that the ERF plays a more significant role, either as a cause, an effect, or both.
- The **fuzzy relation ($\tilde{D}_i-\tilde{R}_i$)** indicates the net causal effect of ERF_i. If ($\tilde{D}_i-\tilde{R}_i$) is positive, ERF_i is a net dispatcher of influence (a cause factor). If it is negative, ERF_i is a net receiver of influence (an effect factor). The magnitude indicates the strength of this net causal role.

These fuzzy vectors $\tilde{D}$, $\tilde{R}$, ($\tilde{D}+\tilde{R}$), and ($\tilde{D}-\tilde{R}$) provide a nuanced, fuzzy understanding of each ERF's role and importance.

4.5.3 Defuzzification of Prominence and Relation Values

To facilitate easier interpretation, ranking, and visualization (particularly for the causal diagram), the fuzzy prominence ($\tilde{D}+\tilde{R}$) and fuzzy relation ($\tilde{D}-\tilde{R}$) vectors were defuzzified into crisp numerical values. The centroid method, a common and robust defuzzification technique, was employed for this purpose. This method calculates a single representative crisp value for each TFN.

Table 4.4 presents the original ERF IDs and their descriptions alongside their defuzzified crisp (D+R) prominence values and (D-R) relation values. These crisp values are crucial for prioritizing the ERFs and categorizing them into cause and effect groups. Figure 4.1 visually represents the prominence (D+R) values, illustrating the relative importance of each ERF. Figure 4.2 displays the relation (D-R) values, highlighting the net causal nature of each ERF, distinguishing dispatcher (cause) factors from receiver (effect) factors..

Table 4.6: Defuzzified Prominence (D+R) and Relation (D-R) Values for ERFs

ERF_ID	**Description**	**(D+R)_crisp (Prominence)**	**(D-R)_crisp (Relation)**
ERF1	Environmental Protection Pressure	10.061452	0.317429
ERF2	Natural Phenomena / Extreme Weather / Force Majeure Events (general)	10.144126	0.029141
ERF3	Storms (wind, dust storms relevant to Addis)	10.087057	-0.067800
ERF4	Humidity Extremes/Variations	9.612392	-0.290222
ERF5	Flood (urban flooding, site-specific)	10.120695	0.309955
ERF6	Landslip / Landslide (site stability, excavation related)	10.121313	0.257502
ERF7	Earthquake / Seismic Activity	10.493590	0.518507
ERF8	Unforeseen / Differing Site Conditions (DSC) (geotechnical, groundwater)	10.430073	-0.199678
ERF9	Adverse Geological Conditions (site-related, e.g., expansive soils)	9.928655	0.707816
ERF10	Site Contamination / Pollution-related Conditions (pre-existing)	9.729045	0.121947
ERF11	Difficulty Accessing Site (due to environmental/site conditions, e.g., narrow urban, topography)	9.995412	-0.184365
ERF12	Pollution from Construction Activities (general, incl. discharge of chemicals/materials)	10.463630	-0.437676
ERF13	Air Pollution (dust, emissions from equipment/vehicles)	10.417039	-0.073599

ERF14	Water Pollution (surface runoff, groundwater contamination)	10.301113	0.279457
ERF15	Land Pollution (spills, improper waste disposal on/off-site)	10.768504	-0.352689
ERF16	Noise Pollution (impact on surrounding areas)	9.914300	0.061240
ERF17	Increased Resource / Raw Material Consumption (inefficient use)	10.192155	-0.000600
ERF18	Increased Water Consumption (for construction processes)	10.069990	0.314606
ERF19	Waste Generation, Management & Disposal Issues (C&D waste)	10.498690	-0.438500
ERF20	Public Health and Safety Risks (from waste, pollution, hazardous materials)	10.576200	-0.720437
ERF21	Challenges with Green/Eco-friendly Materials & Equipment (availability, performance)	10.018706	-0.246463
ERF22	Weak enforcement of existing environmental regulations	10.699756	0.223570
ERF23	Inadequate consideration of urban heat island effect in design	10.180277	-0.057087

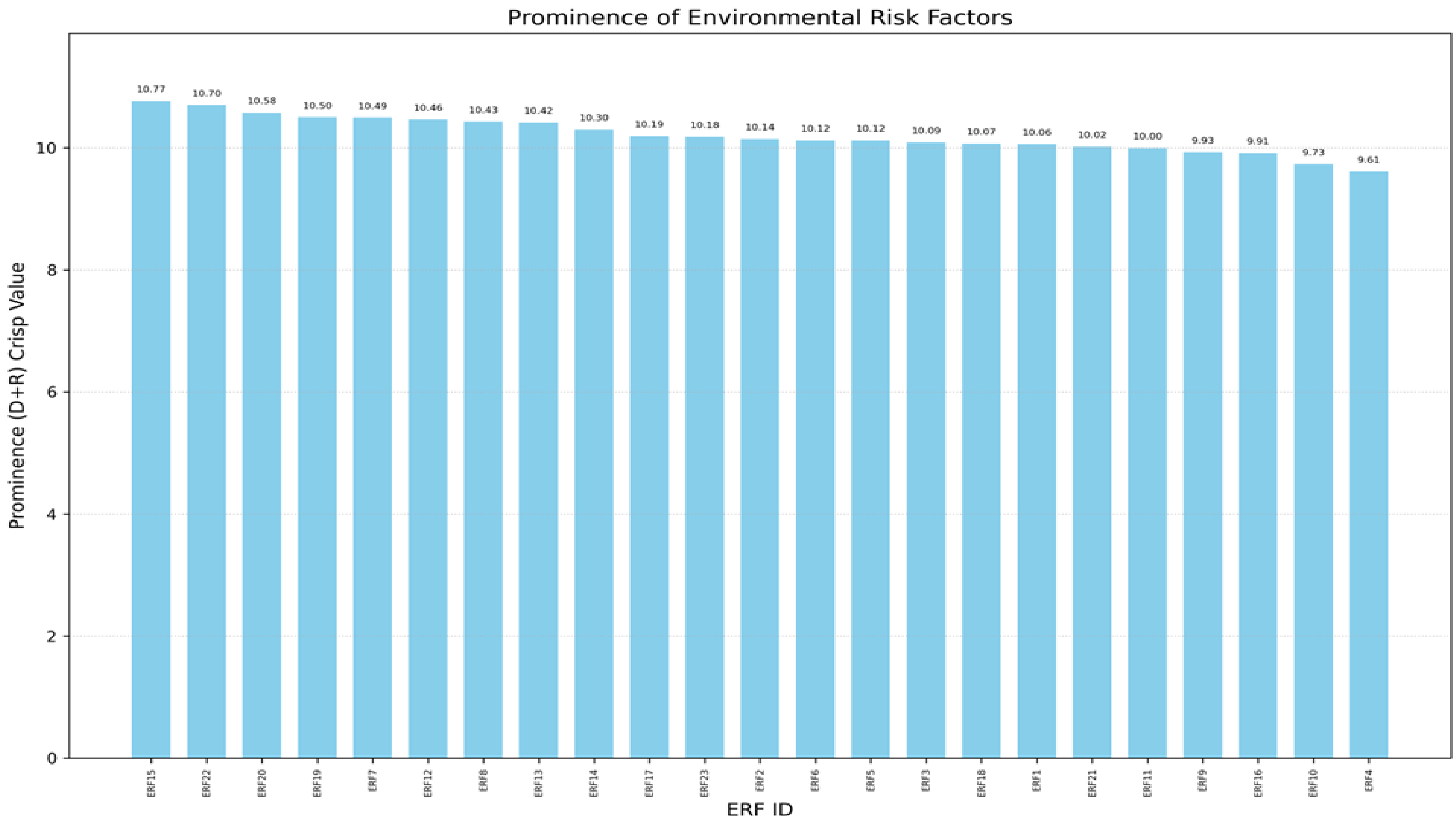


Figure 4.1 illustrates the overall prominence (D+R) of each Environmental Risk Factor, indicating their total influence within the system. Higher bars represent ERFs with greater overall importance.

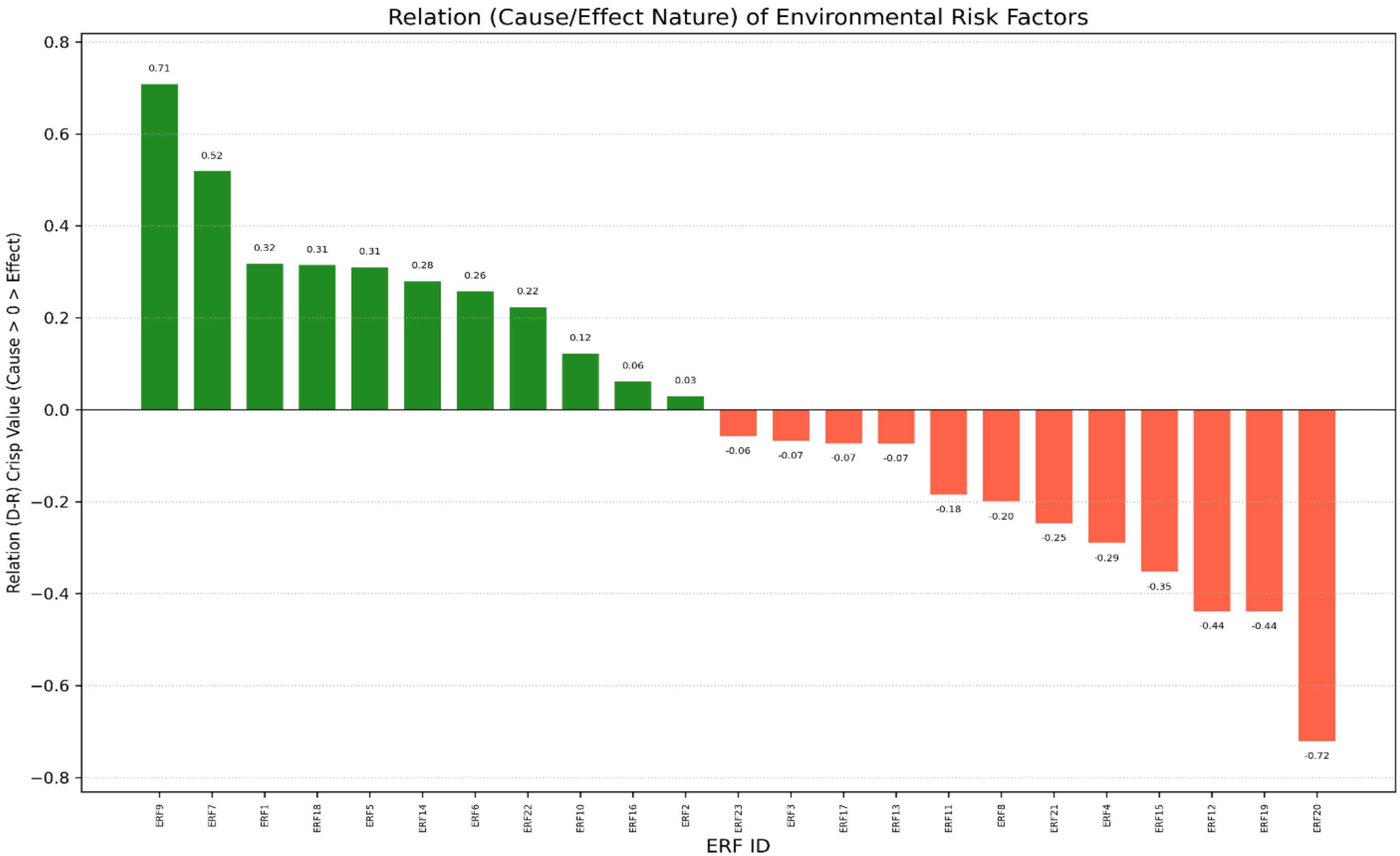


Figure 4.2: Relation (Cause/Effect Nature) of Environmental Risk Factors – Bar Chart based on D-R crisp values, sorted from highest positive to lowest negative.

Figure 4.2 depicts the net causal relation (D-R) for each Environmental Risk Factor. Positive values indicate dispatcher (cause) ERFs, while negative values indicate receiver (effect) ERFs. The magnitude of the bar shows the strength of this causal nature.

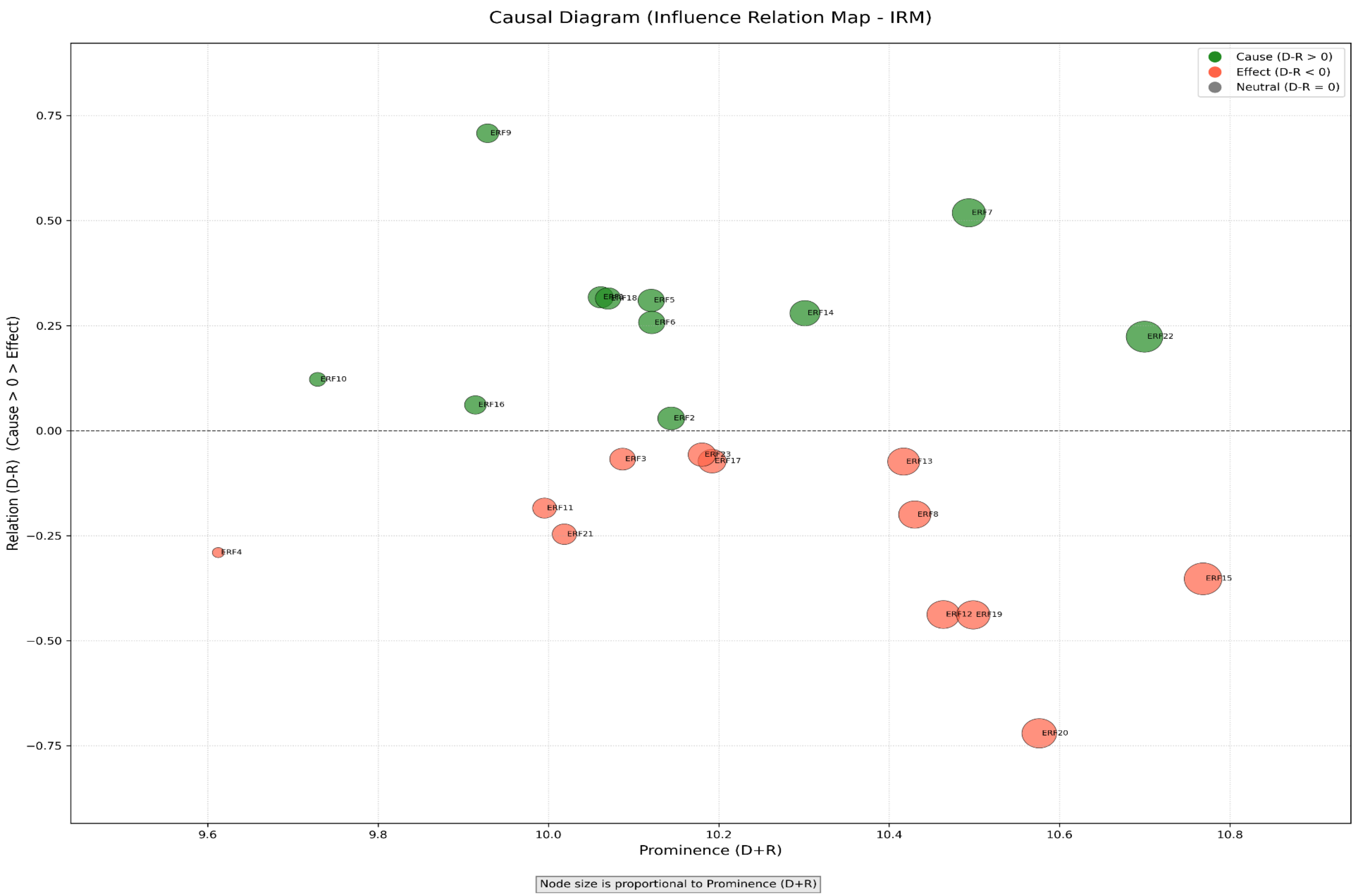
The prominence values (D+R) highlight ERFs such as ERF15 (Land Pollution), ERF22 (Weak enforcement of existing environmental regulations), and ERF20 (Public Health and Safety Risks) as having the highest overall influence within the system of environmental risks for high-rise construction projects in Addis Ababa. The relation values (D-R) identify strong dispatcher ERFs like ERF9 (Adverse Geological Conditions) and ERF7 (Earthquake / Seismic Activity) as key root causes, while ERFs like ERF20 (Public Health and Safety Risks) and ERF19 (Waste Generation, Management & Disposal Issues) emerge as significant net receivers of influence, being heavily impacted by other factors. The implications of these prominence and relation values will be further explored in the causal diagram and discussion sections.

4.5.4 Causal Diagram (Influence Relation Map - IRM)

To visually represent the complex interrelationships among the identified Environmental Risk Factors (ERFs) and to facilitate a clearer understanding of their causal structure, an Influence Relation Map (IRM), also known as a causal diagram, was constructed. This diagram plots each ERF based on its defuzzified prominence (D+R) value on the x-axis and its defuzzified relation (D-R) value on the y-axis. The (D+R) value indicates the overall importance or total influence of an ERF within the system, while the (D-R) value determines its net causal nature – whether it is primarily a 'dispatcher' (cause) of influence or a 'receiver' (effect) of influence.

Figure 4.3 presents the constructed causal diagram for the 23 ERFs. The x-axis represents the Prominence (D+R), indicating the strength of an ERF's total relationships (both dispatched and received). ERFs further to the right on this axis have a higher degree of interaction within the system. The y-axis represents the Relation (D-R), indicating the net influence.

- **Cause (Dispatcher) Group:** ERFs with a positive (D-R) value are plotted above the x-axis. These are considered 'dispatcher' or 'cause' factors, as they exert more influence on other ERFs than they receive.
- **Effect (Receiver) Group:** ERFs with a negative (D-R) value are plotted below the x-axis. These are considered 'receiver' or 'effect' factors, as they are more influenced by other ERFs than they influence others.
- The size of each node in the diagram is proportional to its (D+R) prominence value, visually emphasizing the most influential ERFs.



(Insert Figure 4.3: Causal Diagram (Influence Relation Map - IRM) of Environmental Risk Factors)

Figure 4.3 Causal Diagram (Influence Relation Map - IRM) illustrating the prominence (D+R) and relation (D-R) of the 23 Environmental Risk Factors. The x-axis represents Prominence, and the y-axis represents Relation. Node size is proportional to Prominence. Green nodes are dispatchers, and orange nodes are receivers.

From the causal diagram (Figure 4.3), ERFs can be clearly categorized. For instance, ERF9 (Adverse Geological Conditions) and ERF7 (Earthquake / Seismic Activity) are positioned strongly in the cause group (upper quadrants), indicating they are significant root drivers of other environmental risks. Conversely, ERFs like ERF20 (Public Health and Safety Risks) and ERF19 (Waste Generation, Management & Disposal Issues) are situated in the effect group (lower quadrants), signifying they are predominantly outcomes or consequences of other influencing factors. The diagram provides a strategic overview for identifying critical ERFs that require priority attention for management interventions.

4.5.5 Discussion of Causal Interrelationships

The causal diagram (Figure 4.3) and the underlying (D+R) and (D-R) values (Table 4.4) provide rich insights into the systemic nature of environmental risks in high-rise building construction projects in Addis Ababa. The interpretation of these interrelationships is crucial for developing effective and targeted management strategies.

a) Most Influential ERFs (High Prominence, D+R)

ERFs with high (D+R) values are central to the risk system due to their extensive interactions. As seen in Figure 4.1 and Table 4.4, the most prominent ERFs are ERF15 (Land Pollution, D+R = 10.77), ERF22 (Weak enforcement of existing environmental regulations, D+R = 10.70), ERF20 (Public Health and Safety Risks, D+R = 10.58), ERF19 (Waste Generation, Management & Disposal Issues, D+R = 10.50), and ERF7 (Earthquake / Seismic Activity, D+R = 10.49). These factors, irrespective of being net causes or effects, are highly interconnected within the environmental risk network and warrant significant managerial attention. Their high prominence suggests that changes or interventions related to these ERFs are likely to have widespread repercussions throughout the system.

b) Key Dispatcher (Cause) ERFs (High Positive D-R)

The dispatcher ERFs are the root causes within the system, and addressing them can proactively mitigate a cascade of subsequent risks. Table 4.5 lists the ERFs categorized as dispatchers, ranked by the strength of their net causal influence (D-R).

Table 4.7: Key Dispatcher (Cause) Environmental Risk Factors

Rank (D-R)	**ERF_ID**	**Description**	**(D-R)_crisp (Relation)**	**(D+R)_crisp (Prominence)**
1	ERF9	Adverse Geological Conditions (site-related, e.g., expansive soils)	0.707816	9.928655
2	ERF7	Earthquake / Seismic Activity	0.518507	10.493590
3	ERF1	Environmental Protection Pressure	0.317429	10.061452
4	ERF18	Increased Water Consumption (for construction processes)	0.314606	10.069990
5	ERF5	Flood (urban flooding, site-specific)	0.309955	10.120695
6	ERF14	Water Pollution (surface runoff, groundwater contamination)	0.279457	10.301113
7	ERF6	Landslip / Landslide (site stability, excavation related)	0.257502	10.121313
8	ERF22	Weak enforcement of existing environmental regulations	0.223570	10.699756
9	ERF10	Site Contamination / Pollution-related Conditions (pre-existing)	0.121947	9.729045
10	ERF16	Noise Pollution (impact on surrounding areas)	0.061240	9.914300
11	ERF2	Natural Phenomena / Extreme Weather / Force Majeure Events (general)	0.029141	10.144126

ERF9 (Adverse Geological Conditions) emerges as the most significant dispatcher (D-R = 0.71), indicating that unaddressed geological issues are primary drivers of other environmental

problems. This aligns with studies that often cite unforeseen ground conditions as major risk sources in construction (Amarasekara et al., 2018; Adedokun et al., 2023). Similarly, ERF7 (Earthquake / Seismic Activity, D-R = 0.52) is a strong natural hazard dispatcher. The newly introduced expert-validated ERF22 (Weak enforcement of existing environmental regulations, D-R = 0.22) also features as a notable dispatcher, underscoring the critical role of governance in managing environmental risks, a common theme in developing country contexts (Tessema et al., 2022). Management strategies focusing on these dispatcher ERFs, such as thorough geotechnical investigations for ERF9 or advocating for stronger regulatory oversight for ERF22, could have significant preventative effects.

a) Key Receiver (Effect) ERFs (High Negative D-R)

Receiver ERFs are predominantly influenced by other factors in the system. Managing these often requires reactive or mitigation strategies, as they are symptoms rather than root causes. Table 4.6, derived from `AD5_Effect_Group_Receivers.csv`, lists the ERFs categorized as receivers, ranked by the strength of their net received influence.

Table 4.8: Key Receiver (Effect) Environmental Risk Factors

Rank (D-R)	**ERF_ID**	**Description**	**(D-R)_crisp (Relation)**	**(D+R)_crisp (Prominence)**
1	ERF20	Public Health and Safety Risks (from waste, pollution, hazardous materials)	-0.720437	10.576200
2	ERF19	Waste Generation, Management & Disposal Issues (C&D waste)	-0.438500	10.498690
3	ERF12	Pollution from Construction Activities (general, incl. discharge of chemicals/materials)	-0.437676	10.463630
4	ERF15	Land Pollution (spills, improper waste disposal on/off-site)	-0.352689	10.768504
5	ERF4	Humidity Extremes/Variations	-0.290222	9.612392

6	ERF21	Challenges with Green/Eco-friendly Materials & Equipment (availability, performance)	-0.246463	10.018706
7	ERF8	Unforeseen / Differing Site Conditions (DSC) (geotechnical, groundwater)	-0.199678	10.430073
8	ERF11	Difficulty Accessing Site (due to environmental/site conditions, e.g., narrow urban, topography)	-0.184365	9.995412
9	ERF13	Air Pollution (dust, emissions from equipment/vehicles)	-0.073599	10.417039
10	ERF17	Increased Resource / Raw Material Consumption (inefficient use)	-0.072653	10.192155
11	ERF3	Storms (wind, dust storms relevant to Addis)	-0.067800	10.087057
12	ERF23	Inadequate consideration of urban heat island effect in design	-0.057087	10.180277

ERF20 (Public Health and Safety Risks, D-R = -0.72) is the most significant receiver, heavily impacted by a multitude of other environmental failings such as pollution and waste. This is consistent with literature highlighting the human health impacts of poor environmental management in construction (Shrivastava & Dwivedi, 2024; Adedokun & Egbelakin, 2024). ERF19 (Waste Generation, Management & Disposal Issues, D-R = -0.44) and ERF12 (Pollution from Construction Activities, D-R = -0.44) are also major effect factors, reflecting common challenges in construction waste and pollution control, especially noted in Addis Ababa (Tafesse, 2021; Teferi, 2017). The high prominence of these effect factors (e.g., ERF20, ERF19, ERF15) indicates that while they are outcomes, their occurrence has significant ripple effects, underscoring the need for robust mitigation.

c) Analysis of Significant Direct and Indirect Relationships

The crisp total-relation matrix (T_crisp, Appendix E and summarized for top influences in Appendix F) reveals the strength of both direct and indirect influences. For example, ERF22 (Weak enforcement of existing environmental regulations) has a very strong total influence on ERF15 (Land Pollution, T_crisp = 0.275), suggesting that lax enforcement directly and indirectly contributes significantly to land pollution issues. Similarly, ERF7 (Earthquake / Seismic Activity) strongly influences ERF8 (Unforeseen / Differing Site Conditions, T_crisp = 0.274), indicating that seismic considerations are critical in assessing site conditions. These strong interdependencies, many of which might not be immediately obvious without such systemic analysis, are crucial for understanding how risks propagate and where interventions can be most effective. For instance, while 'Land Pollution' (ERF15) is a major receiver, its strong connection to 'Weak enforcement' (ERF22) suggests that improving enforcement could be a more fundamental solution than solely focusing on site-level pollution cleanup.

Comparing these findings with existing literature, the identification of geological and natural hazards as key dispatchers is common (Kivrak & Udan, 2023). The emergence of 'Weak enforcement' as a strong dispatcher is particularly relevant for developing countries like Ethiopia, where regulatory frameworks may exist but their implementation is a challenge (Tessema et al., 2022). The strong impact on 'Public Health and Safety' and 'Waste Management' as effect factors aligns with global concerns about the construction industry's environmental footprint (Islam et al., 2024). The unique contribution of this study lies in quantifying these interrelationships specifically for high-rise projects in Addis Ababa using the Fuzzy DEMATEL approach, providing a context-specific, data-driven basis for strategic risk management.

4.6 Prioritization of ERFs (Addressing Specific Objective 3)

This section addresses the third specific objective of the study: To prioritize the identified ERFs based on their overall influence (prominence) and net causal effect (relation) as determined by the Fuzzy DEMATEL analysis. The prioritization is primarily based on the defuzzified prominence (D+R) values, which indicate the overall degree of an ERF's involvement and influence within the complex system of environmental risks. ERFs with higher prominence values are considered more critical as they have a greater total sum of influences dispatched and received.

4.6.1 Ranking of ERFs based on Prominence (D+R)

The defuzzified prominence (D+R) values calculated in Section 4.4.5 provide a basis for ranking the 23 Environmental Risk Factors from most to least influential within the context of high-rise building construction projects in Addis Ababa. A higher (D+R) value signifies that an ERF has stronger relationships with other factors, making it a more central component in the overall risk network.

Table 4.7 presents the ERFs ranked in descending order of their prominence (D+R) values. This ranking helps to identify the most influential ERFs that warrant the highest priority for management attention.

Table 4.9: Ranking of Environmental Risk Factors by Prominence (D+R)

Rank	ERF_ID	Description	(D+R)_crisp (Prominence)	(D-R)_crisp (Relation)
1	ERF15	Land Pollution (spills, improper waste disposal on/off-site)	10.768504	-0.352689
2	ERF22	Weak enforcement of existing environmental regulations	10.699756	0.223570
3	ERF20	Public Health and Safety Risks (from waste, pollution, hazardous materials)	10.576200	-0.720437
4	ERF19	Waste Generation, Management & Disposal Issues (C&D waste)	10.498690	-0.438500
5	ERF7	Earthquake / Seismic Activity	10.493590	0.518507
6	ERF12	Pollution from Construction Activities (general, incl. discharge of chemicals/materials)	10.463630	-0.437676
7	ERF8	Unforeseen / Differing Site Conditions	10.430073	-0.199678

		(DSC) (geotechnical, groundwater)		
8	ERF13	Air Pollution (dust, emissions from equipment/vehicles)	10.417039	-0.073599
9	ERF14	Water Pollution (surface runoff, groundwater contamination)	10.301113	0.279457
10	ERF17	Increased Resource / Raw Material Consumption (inefficient use)	10.192155	-0.000600
11	ERF23	Inadequate consideration of urban heat island effect in design	10.180277	-0.057087
12	ERF2	Natural Phenomena / Extreme Weather / Force Majeure Events (general)	10.144126	0.029141
13	ERF6	Landslip / Landslide (site stability, excavation related)	10.121313	0.257502
14	ERF5	Flood (urban flooding, site-specific)	10.120695	0.309955
15	ERF3	Storms (wind, dust storms relevant to Addis)	10.087057	-0.067800
16	ERF18	Increased Water Consumption (for construction processes)	10.069990	0.314606
17	ERF1	Environmental Protection Pressure	10.061452	0.317429
18	ERF21	Challenges with Green/Eco-friendly Materials & Equipment (availability, performance)	10.018706	-0.246463
19	ERF11	Difficulty Accessing Site (due to environmental/site conditions, e.g.,	9.995412	-0.184365

		narrow urban, topography)		
20	ERF9	Adverse Geological Conditions (site-related, e.g., expansive soils)	9.928655	0.707816
21	ERF16	Noise Pollution (impact on surrounding areas)	9.914300	0.061240
22	ERF10	Site Contamination / Pollution-related Conditions (pre-existing)	9.729045	0.121947
23	ERF4	Humidity Extremes/Variations	9.612392	-0.290222

The top-ranked ERFs, based on their prominence values, are ERF15 (Land Pollution), ERF22 (Weak enforcement of existing environmental regulations), ERF20 (Public Health and Safety Risks), ERF19 (Waste Generation, Management & Disposal Issues), and ERF7 (Earthquake / Seismic Activity). These five ERFs exhibit the highest degree of interaction and overall influence within the environmental risk system for high-rise building projects in Addis Ababa.

4.6.2 Interpretation of Prioritized ERFs

The ERFs with high prominence (D+R) values are considered the most critical because their management (or mismanagement) is likely to have the most significant cascading effects throughout the entire system of environmental risks.

- ERF15 (Land Pollution), ranked 1st, is a major concern stemming from various construction activities. Its high prominence suggests it is both a significant outcome of other poor practices and a contributor to further environmental and health issues.
- ERF22 (Weak enforcement of existing environmental regulations), ranked 2nd, is a crucial governance-related factor. Its high prominence highlights that deficiencies in enforcement have widespread implications across many other environmental risks.
- ERF20 (Public Health and Safety Risks), ranked 3rd, underscores the direct human impact of unmanaged environmental risks. Its high prominence signifies its strong linkage with numerous other risk factors such as pollution and waste.

- ERF19 (Waste Generation, Management & Disposal Issues), ranked 4th, is a well-documented challenge in the construction industry, particularly in urban contexts like Addis Ababa. Its prominence indicates its central role in the environmental risk landscape.
- ERF7 (Earthquake / Seismic Activity), ranked 5th, although a natural hazard, is highly prominent due to its potential to interact with and exacerbate numerous site-specific and construction-activity-related risks in a seismically active region.

These top-ranked ERFs are deemed most critical not necessarily because they are all primary causes, but because they are key nodes in the risk network. Effective management strategies must, therefore, give special consideration to these factors due to their overall influence.

4.6.3 Discussion of Prioritization

The prioritization based on prominence (D+R) provides a holistic view of an ERF's importance. It is insightful to relate this prioritization back to the causal analysis (D-R values) to understand the nature of these prominent ERFs.

- Among the top 5 most prominent ERFs, ERF22 (Weak enforcement) and ERF7 (Earthquake / Seismic Activity) are strong dispatchers (positive D-R). This means that focusing on improving regulatory enforcement and robust seismic design and preparedness can have significant preventative impacts on the overall system.
- Conversely, ERF15 (Land Pollution), ERF20 (Public Health and Safety Risks), and ERF19 (Waste Management) are strong receivers (negative D-R). While highly prominent, they are largely outcomes of other factors. This implies that while direct mitigation for these is necessary, addressing their root causes (the dispatcher ERFs) is crucial for long-term effective risk management. For example, the high prominence and receiver nature of ERF15 (Land Pollution) are heavily influenced by dispatcher ERF22 (Weak enforcement), suggesting that tackling enforcement issues is key to reducing land pollution.

This prioritization, therefore, does not simply suggest tackling the most prominent ERFs in isolation. Instead, it implies a strategic approach:

a) Focus on prominent dispatcher ERFs: These are high-leverage points where interventions can yield widespread benefits by preventing a cascade of subsequent risks.
b) Develop robust mitigation and control measures for prominent receiver ERFs: While these are effects, their high prominence means their occurrence has significant consequences and thus they require dedicated management to control their impacts.
c) Understand the pathways: The connections revealed by the total-relation matrix between prominent dispatchers and prominent receivers (as discussed in 4.4.7) inform how interventions in one area will affect another.

The implication for risk management efforts in Addis Ababa's high-rise construction sector is that a multi-pronged strategy is required. This strategy should prioritize strengthening regulatory frameworks and enforcement (ERF22), ensuring robust geological and seismic assessments and designs (ERF9, ERF7), and simultaneously implementing stringent controls and mitigation measures for pollution, waste, and public health impacts (ERF15, ERF20, ERF19). This dual focus on both root causes and critical effects, informed by their overall prominence, forms the basis for the strategic framework developed in Section 4.6.

4.7 Development of a Strategic Framework for Managing Critical ERFs (Addressing Specific Objective 4)

Following the comprehensive identification, causal analysis, and prioritization of Environmental Risk Factors (ERFs) pertinent to high-rise building construction projects in Addis Ababa (as detailed in Sections 4.3, 4.4, and 4.5), this section outlines the development of a strategic framework designed to manage these critical ERFs. This framework aims to translate the analytical insights derived from the Fuzzy DEMATEL methodology into actionable, context-specific management strategies, thereby addressing the fourth specific objective of this research. The framework draws upon the identified causal interrelationships (D-R values), the overall prominence (D+R values) of ERFs, and incorporates established best practices in risk and environmental management from both developing and developed nations' construction sectors.

4.7.1 Introduction to the Framework

The primary purpose of this strategic framework is to provide a structured and systematic approach for stakeholders in Addis Ababa's high-rise construction sector to proactively and effectively manage the most influential ERFs. It emphasizes a dynamic process that integrates risk assessment findings into project planning, execution, and monitoring phases. The framework is conceptualized as a multi-stage process, depicted in Figure 4.4 (as per your thesis structure), which includes foundational principles, core risk management phases, and specific strategy development tailored to the nature of the prioritized ERFs.

4.7.2 Foundational Principles of the Framework

The effectiveness of the proposed framework is underpinned by several foundational principles that should guide its application:

a) Regulatory Compliance and Local Context Awareness: Strategies must align with Ethiopian environmental regulations and be adapted to the specific socio-economic, technical, and institutional realities of Addis Ababa's construction environment.
b) Proactive and Preventative Approach: Emphasis is placed on anticipating and preventing ERFs, particularly those identified as strong 'dispatchers' (causes), rather than solely reacting to their impacts.
c) Stakeholder Collaboration and Communication: Effective ERF management requires robust collaboration and transparent communication among all project stakeholders, including clients, consultants, contractors, regulatory bodies, and the community.
d) Commitment to Sustainable Construction Practices: The framework inherently promotes the adoption of sustainable materials, technologies, and processes to minimize adverse environmental impacts throughout the project lifecycle.
e) Continuous Improvement and Adaptive Management: ERF management is an iterative process. The framework encourages ongoing monitoring, evaluation, and adaptation of strategies based on performance feedback and evolving project conditions.

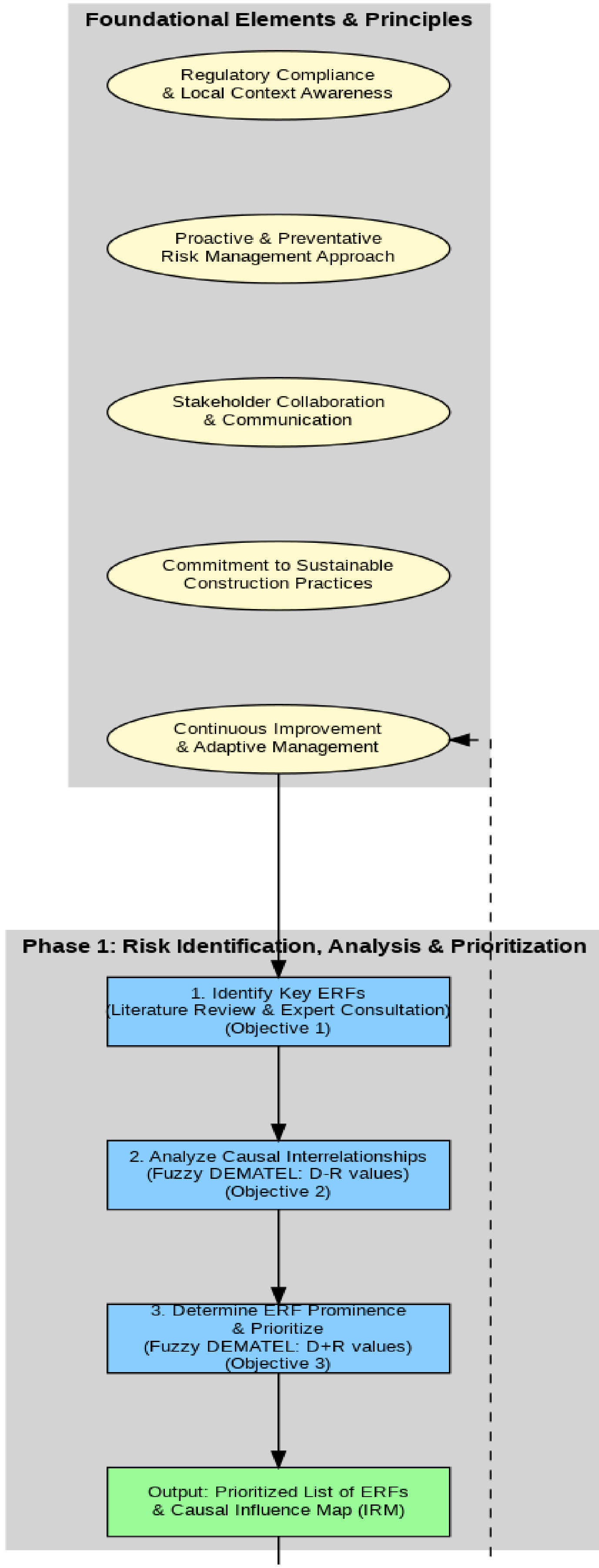
4.7.3 Core Components and Phases of the Framework

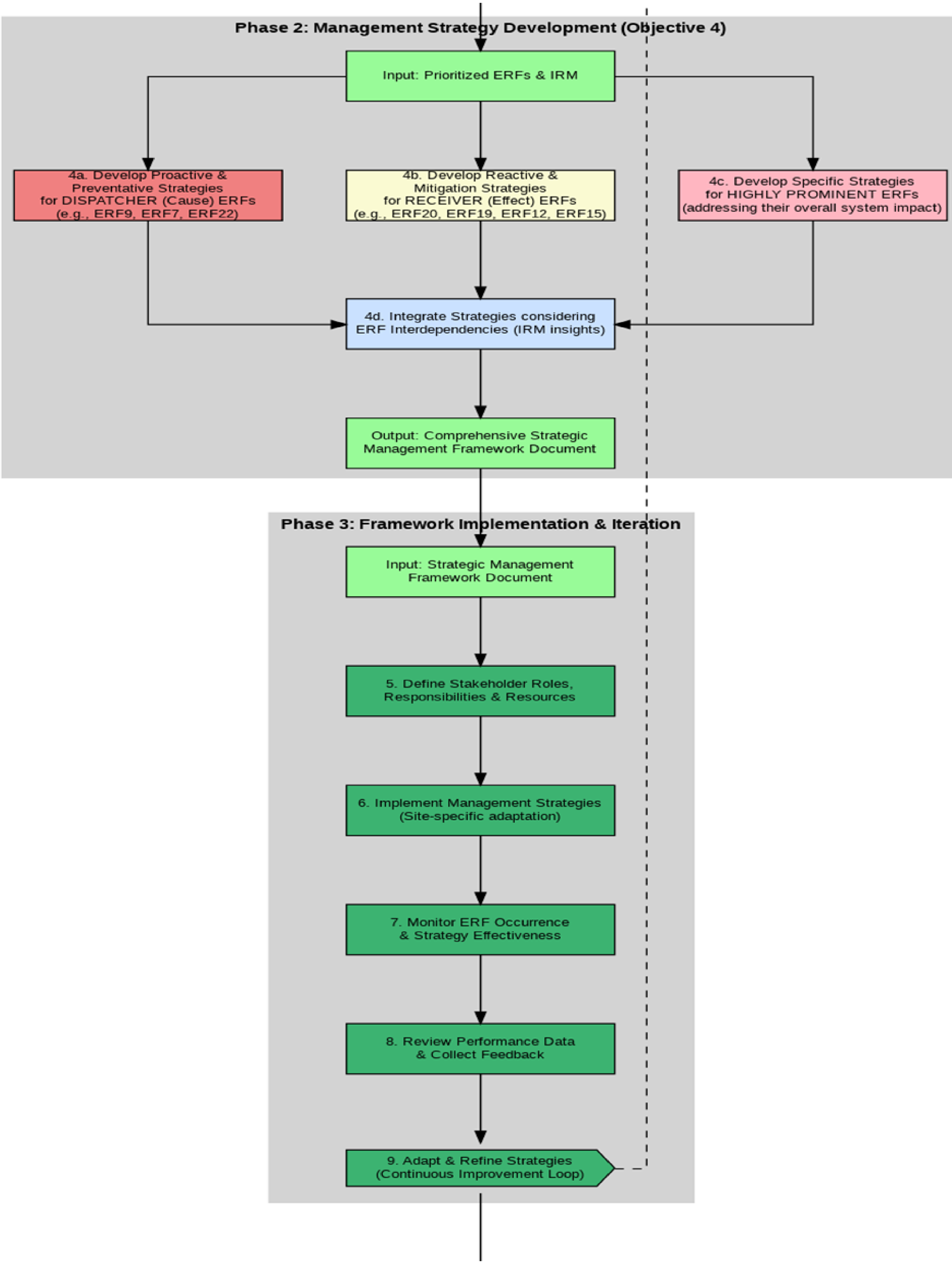
The strategic framework is methodically structured into three primary phases, as visually represented in Figure 4.4, to guide the management of Environmental Risk Factors (ERFs) in high-rise construction.

The initial stage, **Phase 1: Risk Identification, Analysis, and Prioritization**, functions as the crucial input phase. This phase encapsulates the foundational analytical work detailed in Sections 4.3, 4.4, and 4.5 of this thesis. The principal deliverables from this initial phase—namely, the validated compendium of 23 ERFs, the Causal Influence Map (IRM) generated through the Fuzzy DEMATEL methodology, and the hierarchically ordered list of ERFs based on their calculated prominence (D+R) and net causal effect (D-R)—collectively constitute the essential informational basis for the subsequent formulation of management strategies.

Following the input phase, **Phase 2: Management Strategy Development** forms the core of the framework, concentrating on the formulation of targeted interventions. This involves developing distinct approaches tailored to the characteristics of the prioritized ERFs. Specifically, for ERFs identified as 'dispatchers' (causes) exhibiting high positive (D-R) values—such as ERF9 (Adverse Geological Conditions), ERF7 (Earthquake/Seismic Activity), and ERF22 (Weak enforcement of existing environmental regulations)—the framework advocates for proactive and preventative measures. Such measures encompass mandating comprehensive geotechnical investigations and site-specific seismic hazard assessments, instituting stringent design review processes that incorporate advanced engineering solutions for geological and seismic risks, and championing capacity-building initiatives within regulatory bodies to bolster the enforcement of environmental legislation. Conversely, for ERFs characterized as 'receivers' (effects) with high negative (D-R) values—including ERF20 (Public Health and Safety Risks), ERF19 (Waste Generation, Management & Disposal Issues), and ERF12 (Pollution from Construction Activities)—the framework emphasizes the implementation of robust mitigation and control measures. These include the adoption of integrated construction and demolition (C&D) waste management plans focusing on the principles of reduction, reuse, and recycling; the establishment of strict on-site pollution control protocols for air, water, and noise, supported by regular monitoring; and the development and enforcement of comprehensive health and safety plans that explicitly address environmental hazards. Furthermore, ERFs demonstrating high overall prominence (D+R), such as ERF15 (Land Pollution), ERF22, and ERF20, necessitate comprehensive attention due to their significant systemic impact and interconnectedness. Strategies for these highly prominent ERFs must be multifaceted, addressing both their potential causal influences and their susceptibility to other factors; for instance, managing ERF15 (Land Pollution) requires not only reactive site-remediation but also proactive strengthening of enforcement (ERF22) to prevent future contamination. A critical aspect of this phase is the integration of strategies considering ERF interdependencies, utilizing the IRM to understand how interventions targeting one ERF may affect others, thereby fostering an integrated system of risk management rather than isolated actions. For example, enhancing ERF22 (Weak Enforcement) is anticipated to yield positive downstream effects on multiple receiver ERFs like ERF15 and ERF12. The culmination of this phase is the development of a Comprehensive Strategic Management Framework Document, specifically adapted for Addis Ababa's high-rise construction context.

The final stage, **Phase 3: Framework Implementation and Iteration**, addresses the practical application and ongoing refinement of the formulated strategies. This phase commences with the clear delineation of stakeholder roles and responsibilities for the execution, monitoring, and reporting of each strategy, followed by the site-specific adaptation and implementation of these general strategies to suit the unique conditions of individual high-rise projects. A critical component of this phase is the establishment of key performance indicators (KPIs) for monitoring ERF occurrence and evaluating the effectiveness of the implemented measures. This is complemented by the regular analysis of performance data and the solicitation of stakeholder feedback, which collectively inform the iterative process of adapting and refining strategies. This continuous improvement loop ensures the framework's sustained relevance and efficacy in managing environmental risks.


Foundational Elements & Principles
Regulatory Compliance & Local Context Awareness
Proactive & Preventative Risk Management Approach
Stakeholder Collaboration & Communication
Commitment to Sustainable Construction Practices
Continuous Improvement & Adaptive Management
Phase 1: Risk Identification, Analysis & Prioritization
1. Identify Key ERFs (Literature Review & Expert Consultation) (Objective 1)
2. Analyze Causal Interrelationships (Fuzzy DEMATEL: D-R values) (Objective 2)
3. Determine ERF Prominence & Prioritize (Fuzzy DEMATEL: D+R values) (Objective 3)
Output: Prioritized List of ERFs & Causal Influence Map (IRM)


Phase 2: Management Strategy Development (Objective 4)
Input: Prioritized ERFs & IRM
4a. Develop Proactive & Preventative Strategies for DISPATCHER (Cause) ERFs (e.g., ERF9, ERF7, ERF22)
4b. Develop Reactive & Mitigation Strategies for RECEIVER (Effect) ERFs (e.g., ERF20, ERF19, ERF12, ERF15)
4c. Develop Specific Strategies for HIGHLY PROMINENT ERFs (addressing their overall system impact)
4d. Integrate Strategies considering ERF Interdependencies (IRM insights)
Output: Comprehensive Strategic Management Framework Document
Phase 3: Framework Implementation & Iteration
Input: Strategic Management Framework Document
5. Define Stakeholder Roles, Responsibilities & Resources
6. Implement Management Strategies (Site-specific adaptation)
7. Monitor ERF Occurrence & Strategy Effectiveness
8. Review Performance Data & Collect Feedback
9. Adapt & Refine Strategies (Continuous Improvement Loop)

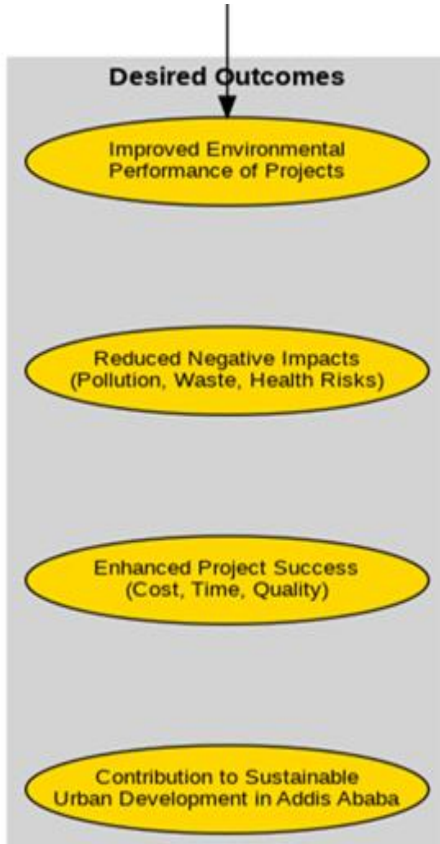


Figure 4.4: Strategic framework for risk management in high-rise construction (Addis Ababa)

4.7.4 Validation of the Strategic Framework

The proposed strategic framework underwent a rigorous validation process to ascertain its clarity, comprehensiveness, practicality, and contextual relevance. This evaluation was conducted by soliciting input from a distinguished panel of five experts, meticulously selected for their extensive experience and diverse professional backgrounds within Addis Ababa's construction industry. The panel comprised a senior academic specializing in construction management, two seasoned practicing consultants with over fifteen years of experience in high-rise projects (one specializing in environmental consultancy and the other in structural and project management), a representative from a pertinent regulatory body overseeing construction and environmental standards, and a senior project manager affiliated with a prominent construction firm engaged in high-rise development. The validation methodology employed semi-structured interviews, during which each constituent component of the framework was systematically discussed. Expert feedback was solicited against a predefined set of evaluative criteria, and the aggregated findings from this validation process are summarized herein.

Regarding clarity, the expert panel generally perceived the framework as clearly structured with well-articulated principles. Minor recommendations were proffered for refining the terminology associated with specific strategies to enhance comprehension among practitioners possessing diverse levels of environmental expertise. In terms of comprehensiveness, the framework was adjudged to adequately address the critical ERFs identified via the Fuzzy DEMATEL analysis. The experts concurred that the strategic focus on dispatcher, receiver, and highly prominent ERFs furnished a robust foundation for strategy development. A suggestion was advanced by one expert to place a more pronounced emphasis on the integration of life-cycle assessment principles within the foundational principle of "Commitment to Sustainable Construction Practices." The practicality of the framework garnered positive reception, particularly its phased methodology and explicit consideration of the local context. Nevertheless, the experts identified potential implementation challenges, including the necessity for augmented technical capacity among certain stakeholders, the initial capital outlay required for specific preventative measures, and the prevailing institutional inertia concerning the rigorous enforcement of environmental management protocols. Concerning its relevance to Addis Ababa, the framework was considered exceptionally pertinent to the extant needs and challenges confronting high-rise building construction in the city. The inclusion of ERF22 (Weak enforcement of existing environmental regulations) and the corresponding strategies to address this factor received particular commendation.

Subsequent to the expert feedback, minor refinements were judiciously incorporated into the framework. These modifications included the explicit inclusion of "capacity building and training" as an overarching implementation enabler and the reinforcement of language pertaining to "resource allocation for ERF management" within the stakeholder roles and responsibilities component. The comprehensive validation process ultimately corroborated the framework's structural soundness and affirmed its potential utility in enhancing environmental risk management practices within the designated sector.

4.7.5 Desired Outcomes of Framework Implementation

The successful implementation of this strategic framework is projected to yield several significant and discernible benefits for high-rise building construction projects situated in Addis Ababa. Foremost among these is an improved environmental performance, characterized by a systematic reduction in pollution, waste generation, and inefficient resource consumption. Concomitantly, reduced negative health and safety impacts are expected, affording better protection for workers and the public from environment-related hazards. The framework is also designed to contribute to enhanced project predictability; by proactively addressing key environmental risks, many of which are known to cause delays and cost overruns, overall project performance concerning time, cost, and quality can be indirectly improved. Furthermore, its application is intended to foster strengthened regulatory compliance, thereby cultivating a culture of adherence to environmental laws and standards. Ultimately, the framework aims to make a substantial contribution to sustainable urban development, aligning high-rise construction practices with the broader imperatives of environmental sustainability and urban resilience within Addis Ababa.

In summation, this strategic framework offers a robust, empirically-grounded, and validated roadmap for the effective management of critical environmental risks. Its adoption and diligent implementation by all pertinent stakeholders are deemed crucial for mitigating the adverse environmental footprint associated with high-rise construction and for promoting a trajectory of more sustainable development within Addis Ababa.

4.8 Discussion and Synthesis of Main Findings

This research embarked on a comprehensive causal analysis and prioritization of Environmental Risk Factors (ERFs) pertinent to high-rise building construction projects in Addis Ababa, employing a Fuzzy DEMATEL approach to inform the development of targeted management strategies. The study's findings, systematically generated through a multi-stage process encompassing ERF identification, causal modeling, prioritization, and strategic framework development, offer significant insights into the complex dynamics of environmental risks within this specific urban construction context.

The initial phase successfully identified a validated list of 23 key ERFs, derived from an extensive literature review and refined through expert consultations. This foundational step (Objective 1) ensured that the subsequent analyses were grounded in factors recognized as both academically relevant and practically significant to Addis Ababa's high-rise sector. The application of the Fuzzy DEMATEL technique (Objective 2) then served to elucidate the intricate causal interrelationships and influence levels among these identified ERFs. This analysis revealed a distinct network structure, categorizing ERFs into 'dispatcher' (cause) and 'receiver' (effect) groups based on their net causal influence (D-R values), and highlighting their overall systemic importance through prominence (D+R) values. The subsequent prioritization of these ERFs (Objective 3), based primarily on their prominence and secondarily on their causal nature, identified a cohort of factors demanding the most urgent managerial attention. This prioritization directly informed the development of a strategic management framework (Objective 4), which proposed targeted interventions for dispatcher, receiver, and highly prominent ERFs, emphasizing proactive, preventative, and mitigative actions.

The interconnections between these findings are pivotal. The specific ERFs identified, such as "Adverse Geological Conditions" (ERF9), "Earthquake/Seismic Activity" (ERF7), and notably "Weak enforcement of existing environmental regulations" (ERF22), emerged as significant dispatchers. Their identification as primary causal agents directly influenced the prioritization process and underscored the necessity for proactive and preventative strategies within the developed framework. For instance, the framework's emphasis on mandating comprehensive geotechnical investigations and advocating for enhanced regulatory enforcement stems directly from the causal influence attributed to ERF9 and ERF22, respectively. Conversely, ERFs like

"Public Health and Safety Risks" (ERF20) and "Waste Generation, Management & Disposal Issues" (ERF19), identified as prominent receivers, dictated the framework's focus on robust mitigation and control measures, such as integrated waste management plans and stringent on-site pollution control. The prominence values further refined this, ensuring that even receiver ERFs with significant systemic impact, like ERF20 and ERF15 ("Land Pollution"), received comprehensive strategic attention due to their high degree of interconnectedness and potential for widespread repercussions.

Comparing these findings with existing literature reveals both confirmations and novel contributions. The identification of geological and natural hazards (ERF9, ERF7) as significant risk drivers aligns with numerous studies in construction risk management (e.g., Adedokun et al., 2023; Kivrak & Udan, 2023), which consistently highlight unforeseen ground conditions and natural phenomena as primary sources of project uncertainty. Similarly, the characterization of waste management (ERF19) and pollution-related issues (ERF12, ERF15) as significant challenges, predominantly as effects, corroborates extensive research on the environmental impact of construction activities, particularly in urban settings (Tafesse, 2021; Islam et al., 2024). However, this study offers a more nuanced understanding through the Fuzzy DEMATEL approach. A key contribution is the empirical identification and quantification of "Weak enforcement of existing environmental regulations" (ERF22) as a potent *dispatcher* of other environmental risks within the specific context of Addis Ababa's high-rise sector. While weak regulatory frameworks are acknowledged as a challenge in developing countries (Tessema et al., 2022), this research elucidates its systemic role in exacerbating a range of other ERFs, such as land pollution and general construction pollution. This finding deviates from studies that might treat regulatory issues primarily as contextual background rather than an active causal factor within the risk network itself. The detailed mapping of interdependencies, such as the strong influence of ERF22 on ERF15, provides a level of granularity often absent in broader risk identification studies.

The implications of these findings are multifaceted. For theory, this research contributes to the understanding of environmental risk interdependencies in high-rise construction projects within developing countries. It underscores the necessity of adopting a systemic perspective, moving beyond the analysis of isolated risk factors to appreciate the complex web of causal relationships. The study particularly highlights the influential role of governance-related factors as systemic drivers within such intricate risk networks. For practice, the findings offer actionable insights for project managers, policymakers, and environmental regulators in Addis Ababa. Project managers are equipped with a prioritized list of ERFs and a framework that emphasizes strategic interventions based on causal roles, enabling more targeted and effective risk management. Policymakers and environmental regulators are provided with empirical evidence supporting the critical need to strengthen enforcement mechanisms (ERF22), as this is shown to be a high-leverage point for mitigating a cascade of other environmental problems. The developed strategic framework itself serves as a practical tool to guide these efforts. Methodologically, this study demonstrates the utility of the Fuzzy DEMATEL approach in the domain of environmental risk management in construction. Its capacity to capture expert subjectivity and model complex causal interdependencies, particularly in data-scarce environments or where issues are characterized by inherent vagueness, proves invaluable. The approach moves beyond simple ranking to reveal the underlying causal architecture of risks, which is crucial for formulating effective and efficient management strategies.

In synthesis, this research has successfully identified, analyzed, and prioritized key environmental risk factors in Addis Ababa's high-rise construction projects, leading to the development of a contextually relevant strategic management framework. The findings confirm several known challenges while also providing novel insights into the causal dynamics and systemic importance of factors such as regulatory enforcement. The study champions a systemic, evidence-based approach to environmental risk management, offering both theoretical contributions and practical guidance for enhancing the sustainability of urban construction in developing city contexts.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

This research successfully addressed its primary objective of conducting a comprehensive causal analysis and prioritization of Environmental Risk Factors (ERFs) inherent in high-rise building construction projects within Addis Ababa, utilizing the Fuzzy DEMATEL methodology to underpin the development of a targeted strategic management framework. The study systematically achieved its specific objectives, yielding significant insights into the complex environmental risk landscape of this rapidly urbanizing context.

In pursuit of its first specific objective, the study meticulously identified and validated a comprehensive list of 23 key ERFs pertinent to high-rise building construction in Addis Ababa. This foundational step, achieved through an exhaustive literature review and refined by expert consultations, ensured that subsequent analyses were grounded in factors recognized for their academic relevance and practical significance within the local construction milieu.

The second and third specific objectives, which focused on determining the causal interrelationships, influence levels, and subsequent prioritization of these ERFs, were accomplished through the rigorous application of the Fuzzy DEMATEL technique. This analysis successfully mapped the intricate network of influences, distinguishing ERFs into influential 'dispatcher' (cause) groups and 'receiver' (effect) groups based on their net causal influence (D-R values). Notably, factors such as 'Adverse Geological Conditions' (ERF9), 'Earthquake/Seismic Activity' (ERF7), and critically, 'Weak enforcement of existing environmental regulations' (ERF22) were identified as significant dispatchers, exerting considerable influence over other ERFs. Conversely, ERFs like 'Public Health and Safety Risks' (ERF20) and 'Waste Generation, Management & Disposal Issues' (ERF19) emerged as prominent receivers, being substantially impacted by other factors within the risk system. The prioritization process, leveraging both the prominence (D+R) and net causal effect (D-R) values, further established a hierarchy of ERFs, highlighting factors such as ERF15 (Land Pollution), ERF22 (Weak enforcement of existing environmental regulations), and ERF20 (Public Health and Safety Risks) as particularly critical due to their high systemic influence and/or significant net causal impact, thereby demanding urgent managerial consideration.

Finally, addressing the fourth specific objective, this research culminated in the development of a strategic management framework tailored for the most critical ERFs identified. This framework, directly informed by the analytical findings on causal roles and prominence, proposes targeted proactive, preventative, and mitigative strategies. Its practical applicability and relevance to the Addis Ababa context were subsequently affirmed through a validation process involving a panel of local industry experts, confirming its potential to guide more effective environmental risk management practices.

In conclusion, this study has systematically achieved all its stated objectives, providing a nuanced, empirically-grounded understanding of the environmental risk landscape in Addis Ababa's high-rise construction sector. The research not only identified and prioritized critical ERFs but also revealed their underlying causal architecture and translated these insights into a validated strategic framework. This offers a significant contribution to both academic knowledge on environmental risk interdependencies in developing urban contexts and practical guidance for enhancing the sustainability of high-rise construction projects in Addis Ababa.

5.2 Recommendations

Based on the comprehensive causal analysis and prioritization of Environmental Risk Factors (ERFs) in Addis Ababa's high-rise building construction sector, and the subsequent development and validation of a strategic management framework, the following recommendations are proffered to key stakeholders to enhance environmental performance and promote sustainable construction practices:

- The study's finding that 'Weak enforcement of existing environmental regulations' (ERF22) acts as a significant 'dispatcher' of other environmental problems, such as 'Land Pollution' (ERF15), underscores a critical leverage point. It is strongly recommended that relevant governmental and regulatory bodies in Addis Ababa prioritize initiatives aimed at bolstering the enforcement of existing environmental laws and standards pertinent to construction. This includes increasing the frequency and rigor of site inspections, enhancing the capacity of regulatory personnel through training and resource allocation, and implementing more stringent and consistent penalties for non-compliance. A concerted effort to improve regulatory oversight will have a cascading positive effect on mitigating a wide array of receiver ERFs.

- Given the significant causal influence of 'Adverse Geological Conditions' (ERF9) and 'Earthquake/Seismic Activity' (ERF7), it is recommended that project approval processes for high-rise buildings in Addis Ababa mandate more comprehensive and site-specific geotechnical investigations and seismic hazard assessments. These assessments should not be mere formalities but should rigorously inform project design and construction methodologies. Design review processes should be made more stringent to ensure that advanced engineering solutions addressing these dispatcher risks are adequately incorporated.
- ERFs such as 'Public Health and Safety Risks' (ERF20), 'Waste Generation, Management & Disposal Issues' (ERF19), and 'Land Pollution' (ERF15), identified as highly prominent and significant receivers of influence, demand robust and integrated mitigation strategies. Project developers and contractors are urged to adopt comprehensive Construction and Demolition (C&D) waste management plans focusing on the 3Rs (Reduce, Reuse, Recycle) from the project's inception. Furthermore, strict on-site pollution control protocols for air, water, and noise, coupled with regular, independent monitoring, should be standard practice. Comprehensive health and safety plans must explicitly address the environmental hazards identified in this study as contributing to public and worker health risks.
- The effective management of the complex web of ERFs, as revealed by the Fuzzy DEMATEL analysis, necessitates enhanced collaboration and communication among all project stakeholders. It is recommended that platforms for regular dialogue between developers, consultants, contractors, regulatory agencies, and community representatives be established or strengthened. Furthermore, targeted capacity-building programs focusing on environmental risk identification, assessment, and the implementation of the proposed strategic framework should be developed for construction professionals and regulatory staff in Addis Ababa. This will improve the collective ability to address ERFs proactively and effectively.
- The strategic framework developed in this research, which has been validated by local experts for its clarity, comprehensiveness, practicality, and relevance, offers a valuable

tool for improving ERF management. It is recommended that industry associations, academic institutions, and relevant government ministries in Ethiopia consider adopting and disseminating this framework. Tailoring its application to specific project contexts and integrating it into standard project management protocols will be crucial for its successful uptake and impact.

- Recognizing that the environmental risk landscape can evolve, it is recommended that a culture of continuous improvement, as embedded in the proposed framework's third phase (Implementation and Iteration), be actively fostered. This involves systematically monitoring ERF occurrence, evaluating the effectiveness of implemented strategies through Key Performance Indicators (KPIs), and adapting management approaches based on performance data and lessons learned.

5.3 Recommendation for Future Research Works

Although this study offers valuable insights into Environmental Risk Factors (ERFs) in Addis Ababa's high-rise construction, its limitations suggest several directions for future research to deepen understanding and enhance environmental risk management in broader contexts.

- Firstly, future research should broaden the geographical and contextual scope. Replicating this Fuzzy DEMATEL methodology in other Ethiopian cities, urban centers in other developing nations, or across different construction typologies (e.g., infrastructure, large-scale residential) would improve the generalizability of findings and identify context-specific ERF nuances.
- Secondly, enhancing expert panel diversity and further investigating subjectivity is recommended. Employing larger, more diverse panels incorporating varied stakeholder perspectives (e.g., community, material suppliers) could reveal different ERF perceptions. Integrating Fuzzy DEMATEL with other MCDM techniques or conducting sensitivity analyses could also help mitigate inherent subjectivity in expert judgments.
- Thirdly, longitudinal studies and dynamic risk assessment are needed. As ERFs and their perceived importance evolve with changing conditions, longitudinal studies tracking ERF evolution and management strategy effectiveness across project phases and over time would provide crucial insights into their temporal dynamics and lifecycle impacts.

- Fourthly, future work should focus on quantitative impact assessment and cost-benefit analysis of mitigation strategies. While this study prioritized ERFs by perceived influence, quantifying their actual financial, schedule, health, and environmental impacts using historical project data is essential. Detailed cost-benefit analyses of proposed mitigation strategies would also offer stronger economic justification for their adoption.
- Fifthly, empirical investigation of the developed framework's implementation and effectiveness is critical. Action research or case studies applying the framework to live high-rise projects in Addis Ababa could assess its efficacy, identify practical challenges and enablers, and refine it based on real-world application, including the development of Key Performance Indicators (KPIs).
- Finally, exploring the role of advanced technologies in ERF management presents a promising avenue. Investigating the potential of technologies like BIM, IoT, AI-driven analytics, and drones to enhance ERF identification, monitoring, and management in Addis Ababa's high-rise projects, including their feasibility and stakeholder readiness, would be beneficial.

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APPENDIX

Appendix A. Expert Consultations

Validation and Refinement of Environmental Risk Factors for High-Rise Building Construction Projects in Addis Ababa (Objective 1)

Student (Researcher) – Elias Ketsela

Thesis Title

"Analyzing and Prioritizing Environmental Risk Factors for High-Rise Building Construction Projects in Addis Ababa: An Integrated Fuzzy DEMATEL and Fuzzy AHP Methodology"

Adama Science and Technology University
School of Civil Engineering and Architecture
Department of Civil Engineering

1. Introduction and Purpose of this Consultation

Dear Expert,

Thank you for agreeing to participate in this crucial phase of my Master of Science research in Construction Engineering and Management. My thesis aims to comprehensively analyze and prioritize the Environmental Risk Factors (ERFs) affecting high-rise building construction projects in Addis Ababa, Ethiopia. The ultimate goal is to develop a strategic framework for managing the most critical ERFs, employing an integrated Fuzzy DEMATEL and Fuzzy AHP methodology.

This expert consultation is specifically designed to achieve the first objective of my study: To identify the key Environmental Risk Factors (ERFs) pertinent to high-rise building construction projects in Addis Ababa.

Your extensive experience and knowledge in the Ethiopian construction sector, particularly concerning high-rise buildings and/or environmental aspects, are invaluable. Your input will help validate, refine, and reduce an initial list of ERFs compiled from a comprehensive literature review (presented as Table 2.1 in my thesis progress, and reproduced below). The outcome of this consultation will be a robust and contextually relevant list of ERFs that will form the basis for the subsequent Fuzzy DEMATEL and Fuzzy AHP analyses.

2. Respondent Profiles

I. Personal and Professional Background

A. Your Current Primary Role/Position:

[ ] Contractor / Construction Manager

[ ] Consultant (e.g., Design, Engineering, Project Management, Environmental)

[ ] Academic / Researcher

[ ] Government Agency Representative / Regulator

[ ] Environmental Specialist / Scientist

[ ] Real Estate Developer

[ ] Other (Please specify): ____________________________________

B. Type of Organization you primarily work for/with:

[ ] Private Construction Company (Contractor)

[ ] Private Consultancy Firm

[ ] Government Ministry / Agency

[ ] Public Enterprise

[ ] Academic Institution

[ ] Non-Governmental Organization (NGO)

[ ] Real Estate Development Company

[ ] Other (Please specify): ____________________________________

II. Experience

A. Total years of experience in the construction sector: _______ years

B. Years of experience specifically with High-Rise Building Projects (15 stories < High Rise Building < 45 Stories, according to FDRE Directive 649/2021): _______ years

C. Years of experience specifically dealing with Environmental Aspects/Risks in construction projects: _______ years

III. Educational Background and Familiarity with Key Concepts

A. Highest Educational Qualification Attained:

[ ] Diploma

[ ] Bachelor's Degree (BSc, BA, B.Eng, etc.)

[ ] Master's Degree (MSc, MA, M.Eng, MBA, etc.)

[ ] Doctoral Degree (PhD, D.Eng, etc.)

[ ] Professional Certification (Please specify if relevant): _______________________

[ ] Other (Please specify): ___________________________________

3. Instructions for Experts

You are presented with a list of potential Environmental Risk Factors (ERFs) in Table below (under Part 1), derived from existing literature. For each ERF, please consider its specific applicability and importance to high-rise building construction projects within the context of Addis Ababa.

Please evaluate each ERF based on the following criteria:

A. Relevance: How relevant is this ERF to high-rise building construction projects in Addis Ababa? Please rate:
   - 3 = Highly Relevant, 2 = Moderately Relevant, 1 = Slightly Relevant, 0 = Not Relevant

B. Significance: Assuming the ERF is relevant, what is its potential significance or level of impact on high-rise building projects in Addis Ababa if not properly managed? Please rate:
   - 3 = High Significance, 2 = Moderate Significance, 1 = Low Significance, 0 = No Significance

C. Clarity & Distinctness: Is the wording of the ERF clear and unambiguous? Is it a distinct factor, or does it significantly overlap with other ERFs in the list? Please comment:
   - e.g., "Clear," "Needs rewording to X," "Overlaps with ERF #Y," "Merge with ERF #Z")

D. Recommendation for this Study: Based on your assessment, should this ERF be (Please select one):

- Keep / Keep with modification (specify in comments) / Remove / Merge (specify which ERF to merge with)

E. Comments/Justification: Please provide any further comments, justifications for your ratings, suggestions for rewording, or reasons for removal/merging.

After evaluating the provided list, please proceed to Part 2 to suggest any additional ERFs you believe are missing but are critical for high-rise projects in Addis Ababa.

4. Timeframe

We kindly request you to complete and return this guide by 1week time.

Part 1. Evaluation of Preliminarily Identified Environmental Risk Factors (ERFs) (Table 1)

(Based on Table 2.1 from the Literature Review)

No.	Environmental Risk Factor (ERF)	A. Relevance (0-3)	B. Significance (0-3)	C. Clarity & Distinctness (Comment)	D.Recommendation (Keep/Modify/Remove/Merge)	E. Comments / Justification
Category 1: Environmental Risks (General & Regulatory)						
1.1	Environmental Risk / Concerns (as a broad category)					*Note: Consider if this is too broad and should be broken down or removed if covered by specifics.*
1.2	Environmental Protection Pressure					
1.3	Environmental Hazards of the Project (general)					*Note: How is this different from 1.1? Consider for merging/clarification.*
1.4	Environmental Regulations and Permitting Procedures					
1.5	Project Affects Employees' Health (environmental causes)					
Category 2: Natural Phenomena / Weather Risks						
2.1	Natural Phenomena / Extreme Weather / Force Majeure Events (general)					
2.2	Adverse / Unexpected Weather Conditions (general)					*Note: Consider merging with 2.1 if too similar for Addis context.*

2.3	Rain / Precipitation (including prolonged, intense)					
2.4	Storms (wind, dust storms relevant to Addis)					
2.5	Temperature Extremes/Variations					
2.6	Humidity Extremes/Variations					
2.7	Wind (including strong winds at height for high-rise)					
2.8	Climate Change Impacts (long-term shifts affecting design/materials)					
2.9	Flood (urban flooding, site-specific)					
2.10	Fire (natural, e.g., wildfire affecting nearby areas/materials storage)					
2.11	Landslip / Landslide (site stability, excavation related)					
2.12	Earthquake / Seismic Activity					
Category 3: Site-Specific Environmental & Physical Risks						
3.1	Unforeseen / Differing Site Conditions (DSC) (geotechnical, groundwater)					
3.2	Adverse Geological Conditions (site-related, e.g., expansive soils)					*Note: Consider overlap with 3.1.*
3.3	Site Contamination / Pollution-related Conditions (pre-existing)					

3.4	Difficulty Accessing Site (due to environmental/site conditions, e.g., narrow urban, topography)					
Category 4: Environmental Impacts & Resource-Related Risks						
4.1	Pollution from Construction Activities (general, incl. discharge of chemicals/materials)					
4.2	Air Pollution (dust, emissions from equipment/vehicles)					
4.3	Water Pollution (surface runoff, groundwater contamination)					
4.4	Land Pollution (spills, improper waste disposal on/off-site)					
4.5	Noise Pollution (impact on surrounding areas)					
4.6	Vibration (from piling, heavy machinery, blasting if any)					*Added as distinct from noise, often relevant for high-rise foundations & urban settings.*
4.7	Increased Resource / Raw Material Consumption (inefficient use)					
4.8	Increased Water Consumption (for construction processes)					
4.9	Waste Generation, Management & Disposal Issues (C&D waste)					
4.10	Impact on Flora and Fauna (site clearing, habitat disruption)					

4.11	Socio-cultural Impact (from environmental disruption, e.g., impact on heritage, community displacement)					
4.12	Public Health and Safety Risks (from waste, pollution, hazardous materials)					
Category 5: Risks Related to Sustainable/Green Practices						
5.1	Challenges with Green/Eco-friendly Materials & Equipment (availability, performance)					
5.2	Lack of Availability (of sustainable options/expertise)					*Note: Could be part of 5.1. Consider merging.*
5.3	High Costs / Barrier to Adoption (of sustainable practices/materials)					
5.4	Inadequate Local Standards/Guidelines for Green Construction					*Added as potentially relevant for Addis Ababa context.*

Part 2: Identification of Additional Environmental Risk Factors (ERFs)

Based on your experience with high-rise building construction projects in Addis Ababa, are there any other significant Environmental Risk Factors that are NOT included in the list above? If so, please list them below with a brief description and justification for their inclusion.

No.	Proposed Additional ERF	Description / Justification for relevance to Addis Ababa High-Rise Context
1.		
2.		
3.		
4		
5		

5. Confidentiality and Use of Data

All responses will be treated with the strictest confidentiality. Your name and affiliation will not be directly linked to your specific responses in the final thesis or any publications without your explicit consent. The aggregated and anonymized findings from this consultation will be used to develop a refined list of ERFs for the subsequent stages of this research.

6. Submission

Please return the completed guide via email to [Eliask.bruba1219@gmail.com] by 1 week period.

Thank you once again for your invaluable contribution to this research.

Sincerely,

Elias Ketsela

M.Sc. Candidate, Construction Engineering and Management

Adama Science and Technology University

Phone Number - +251911894361

Appendix B. Fuzzy Analytic Hierarchy Process (AHP) Questionnaire

Analyzing and Prioritizing Environmental Risk Factors for High-Rise Building Construction Projects in Addis Ababa

I. Assumptions

- Goal of Fuzzy AHP: To determine the relative priority weights of the identified Environmental Risk Factors (ERFs) based on their *overall impact on high-rise building construction projects in Addis Ababa*.
- Experts: The form is designed for individual completion by construction industry and environmental experts familiar with high-rise projects in Addis Ababa.
- Fuzzy Scale: We will use Triangular Fuzzy Numbers (TFNs) for the pairwise comparisons. A common 9-level linguistic scale will be provided.
- Grouping: The 23 ERFs will be categorized into four distinct groups for manageable pairwise comparisons. The comparisons will be made *within* each group. This means we will get priorities within each group. If you later need overall priorities, you would typically do another AHP level to compare the *groups themselves*, or use a different integration method. For now, we'll focus on within-group priorities as per the "four distinct/different independent pairwise comparison matrices" requirement.
- Number of ERFs: 23 ERFs as per the CSV description.

II. Final ERF List (based on your CSV description)

The followings are the list of 23 ERFs based on the CSV description to make the form concrete.

- ERF1: Environmental Protection Pressure
- ERF2: Natural Phenomena / Extreme Weather (general)
- ERF3: Storms (wind, dust storms)
- ERF4: Humidity Extremes/Variations
- ERF5: Flood (urban flooding, site-specific)
- ERF6: Landslip / Landslide
- ERF7: Earthquake / Seismic Activity
- ERF8: Unforeseen / Differing Site Conditions (DSC)

- ERF9: Adverse Geological Conditions
- ERF10: Site Contamination / Pollution-related Conditions
- ERF11: Difficulty Accessing Site
- ERF12: Pollution from Construction Activities (general)
- ERF13: Air Pollution (dust, emissions)
- ERF14: Water Pollution (surface runoff, groundwater)
- ERF15: Land Pollution (spills, improper waste disposal)
- ERF16: Noise Pollution
- ERF17: Increased Resource / Raw Material Consumption
- ERF18: Increased Water Consumption
- ERF19: Waste Generation, Management & Disposal Issues
- ERF20: Public Health and Safety Risks (from waste, pollution)
- ERF21: Challenges with Green/Eco-friendly Materials & Equipment
- ERF22: Weak enforcement of existing environmental regulations
- ERF23: Inadequate consideration of urban heat island effect

III. Grouping for the 23 ERFs

To create 4 distinct matrices, we'll group these.

- **Group A: Regulatory, General Weather & Site Access Risks (6 ERFs)**
    - → A1: ERF1 - Environmental Protection Pressure
    - → A2: ERF2 - Natural Phenomena / Extreme Weather (general)
    - → A3: ERF3 - Storms (wind, dust storms)
    - → A4: ERF11 - Difficulty Accessing Site
    - → A5: ERF22 - Weak enforcement of existing environmental regulations
    - → A6: ERF23 - Inadequate consideration of urban heat island effect
- **Group B: Site-Specific & Geohazard Risks (6 ERFs)**
    - → B1: ERF5 - Flood (urban flooding, site-specific)
    - → B2: ERF6 - Landslip / Landslide
    - → B3: ERF7 - Earthquake / Seismic Activity
    - → B4: ERF8 - Unforeseen / Differing Site Conditions (DSC)
    - → B5: ERF9 - Adverse Geological Conditions

→ B6: ERF10 - Site Contamination / Pollution-related Conditions

- **Group C: Direct Construction Pollution & Health Risks (6 ERFs)**
  - → C1: ERF12 - Pollution from Construction Activities (general)
  - → C2: ERF13 - Air Pollution (dust, emissions)
  - → C3: ERF14 - Water Pollution (surface runoff, groundwater)
  - → C4: ERF15 - Land Pollution (spills, improper waste disposal)
  - → C5: ERF16 - Noise Pollution
  - → C6: ERF20 - Public Health and Safety Risks (from waste, pollution)
- **Group D: Resource, Waste & Green Practice Risks (5 ERFs)**
  - → D1: ERF4 - Humidity Extremes/Variations (can affect material storage/curing & green materials)
  - → D2: ERF17 - Increased Resource / Raw Material Consumption
  - → D3: ERF18 - Increased Water Consumption
  - → D4: ERF19 - Waste Generation, Management & Disposal Issues
  - → D5: ERF21 - Challenges with Green/Eco-friendly Materials & Equipment

This grouping creates 4 groups with 6, 6, 6, and 5 ERFs respectively, which is manageable for pairwise comparison.

1. Introduction

Dear Expert,

Thank you for agreeing to participate in this crucial research study. Your expertise and insights are invaluable for analyzing and prioritizing environmental risk factors (ERFs) affecting high-rise building construction projects in Addis Ababa. This questionnaire is part of a Master's thesis aimed at developing a strategic framework for managing these risks.

Objective of this Questionnaire –

- To determine the relative importance (priority weights) of various identified Environmental Risk Factors (ERFs) based on their *overall impact on high-rise building construction projects in Addis Ababa*.

Instructions –

- This questionnaire uses the Fuzzy Analytic Hierarchy Process (AHP) methodology. You will be asked to make pairwise comparisons between ERFs *within* predefined groups. For each pair, please indicate which ERF you believe has a greater overall impact on high-rise building projects and by how much, using the linguistic scale provided below.

The linguistic scale is associated with Triangular Fuzzy Numbers (TFNs) in the form (l, m, u), where 'l' is the lower bound, 'm' is the most plausible value, and 'u' is the upper bound.

Linguistic Scale for Pairwise Comparison and Corresponding TFNs:

Linguistic Term	**TFN (l, m, u)**	**Meaning**
Equally Important (EI)	(1, 1, 1)	Both ERFs have equal impact.
Weakly More Important (WMI)	(1, 2, 3)	One ERF is weakly more impactful than the other.
Fairly More Important (FMI)	(2, 3, 4)	Experience and judgment slightly favor one ERF over another.
Moderately More Important (MMI)	(3, 4, 5)	Experience and judgment moderately favor one ERF over another.
Strongly More Important (SMI)	(4, 5, 6)	One ERF is strongly more impactful.
Very Strongly More Imp. (VSMI)	(5, 6, 7)	One ERF is very strongly more impactful.

Demonstrably More Imp. (DMI)	(6, 7, 8)	The evidence favoring one ERF over another is of the highest possible order of affirmation.
Extremely More Important (EMI)	(7, 8, 9)	The evidence favoring one ERF over another is of the highest possible order of affirmation.
Absolutely More Important (AMI)	(9, 9, 9)	The evidence favoring one ERF over another is of the highest possible order of affirmation.

If ERF A is "Weakly More Important" than ERF B (1,2,3), then ERF B is "Weakly Less Important" than ERF A, which would be the reciprocal fuzzy number (1/3, 1/2, 1/1). You only need to fill one side of the comparison.

How to Fill the Matrices – For each matrix:

- The ERFs are listed on the rows and columns.
- Compare the ERF in the ROW with the ERF in the COLUMN.
- Ask yourself: *"With respect to their overall impact on high-rise building construction projects in Addis Ababa, how much more important is the ROW ERF compared to the COLUMN ERF?"*
- Select the appropriate linguistic term from the scale. You can write the abbreviation (e.g., SMI) or the TFN directly into the cell.

Confidentiality – All responses will be kept strictly confidential and will be used for academic research purposes only. Your identity will not be revealed in any publication resulting from this study.

Time – It is estimated that this questionnaire will take approximately 30-45 minutes to complete.

Contact – If you have any questions, please do not hesitate to contact Elias Ketsela at [Eliask.bruba1219@gmail.com] or [+251912289777].

Part 1: Pairwise Comparison of Environmental Risk Factors (ERFs)

Goal for all comparisons: To assess the relative importance of ERFs based on their *overall impact on high-rise building construction projects in Addis Ababa*.

Matrix 1: Group A - Regulatory, General Weather & Site Access Risks

ERF Codes & Descriptions for Group A:

- **A1:** Environmental Protection Pressure
- **A2:** Natural Phenomena / Extreme Weather (general)
- **A3:** Storms (wind, dust storms)
- **A4:** Difficulty Accessing Site
- **A5:** Weak enforcement of existing environmental regulations
- **A6:** Inadequate consideration of urban heat island effect

Compared to → How important is ↓	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**
A1	EI(1,1,1)					
A2		EI(1,1,1)				
A3			EI(1,1,1)			
A4				EI(1,1,1)		
A5					EI(1,1,1)	
A6						EI(1,1,1)

Matrix 2: Group B - Site-Specific & Geohazard Risks
ERF Codes & Descriptions for Group B:

- **B1:** Flood (urban flooding, site-specific)
- **B2:** Landslip / Landslide
- **B3:** Earthquake / Seismic Activity
- **B4:** Unforeseen / Differing Site Conditions (DSC)
- **B5:** Adverse Geological Conditions
- **B6:** Site Contamination / Pollution-related Conditions

Compared to → How important is ↓	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**
B1	EI(1,1,1)					
B2		EI(1,1,1)				
B3			EI(1,1,1)			
B4				EI(1,1,1)		
B5					EI(1,1,1)	
B6						EI(1,1,1)

Matrix 3: Group C - Direct Construction Pollution & Health Risks

ERF Codes & Descriptions for Group C:

- **C1:** Pollution from Construction Activities (general)
- **C2:** Air Pollution (dust, emissions)
- **C3:** Water Pollution (surface runoff, groundwater)
- **C4:** Land Pollution (spills, improper waste disposal)
- **C5:** Noise Pollution
- **C6:** Public Health and Safety Risks (from waste, pollution)

Compared to → How important is ↓	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
C1	EI(1,1,1)					
C2		EI(1,1,1)				
C3			EI(1,1,1)			
C4				EI(1,1,1)		
C5					EI(1,1,1)	
C6						EI(1,1,1)

Matrix 4: Group D - Resource, Waste & Green Practice Risks

ERF Codes & Descriptions for Group D:

- **D1:** Humidity Extremes/Variations
- **D2:** Increased Resource / Raw Material Consumption
- **D3:** Increased Water Consumption
- **D4:** Waste Generation, Management & Disposal Issues
- **D5:** Challenges with Green/Eco-friendly Materials & Equipment

Compared to → How important is ↓	**D1**	**D2**	**D3**	**D4**	**D5**
D1	EI(1,1,1)				
D2		EI(1,1,1)			
D3			EI(1,1,1)		
D4				EI(1,1,1)	
D5					EI(1,1,1)

Thank you very much for your time and valuable contribution to this research!