

Risk Dynamics and Performance of Geothermal Drilling Projects in Menengai, Nakuru County, Kenya.

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ABSTRACT

Operational risks play a pivotal role in determining the success or failure of drilling projects, both globally and in Kenya, due to the complexity, high costs, and safety-critical nature of these ventures. These risks encompass equipment failures, geological challenges, human error, supply chain disruptions, regulatory non-compliance, and environmental hazards. However, there is a lack of comprehensive research that specifically examines how operational risks, such as technical challenges, environmental and safety issues, human resource limitations, and logistical issues, affect geothermal drilling project outcomes in Kenya, especially in the Menengai Geothermal field in Nakuru County, Kenya. Therefore, the general objective of this study was to establish the influence of operations risk factors on geothermal drilling project success in Menengai Geothermal Field in Nakuru County. It specifically seeks to determine the influence of; technical risks, environment and safety risks, logistics risks, and human resource risks on Geothermal Drilling Project Success in Menengai Geothermal Field. This study was anchored on two principal theoretical foundations: Risk Management Theory and Project Success Theory. The research employed a convergent parallel mixed-methods design, where both qualitative and quantitative data were collected comprises concurrently, analyzed separately, and then merged during interpretation. The target population stakeholders involved in geothermal drilling at Menengai Geothermal fields. These included project managers, engineers, safety officers, logistics personnel, and risk managers from the Geothermal Development Company (GDC), all who total 167 in number. A sample of 116 respondents was used. For the qualitative component, purposive sampling was employed to identify approximately 17 key informants. The study employed two main instruments: a structured questionnaire for quantitative data and an interview guide for qualitative insights. Both descriptive and inferential statistical methods were used to analyse the quantitative data which were then presented in tables and discussed. Thematic content analysis was also used to analyze qualitative data. The study established that technical risks—particularly equipment failures, wellbore instability, and geological uncertainties—are significant determinants of geothermal drilling project success in the Menengai Geothermal Field. The findings also revealed that environmental and safety risks significantly influence geothermal drilling project success in the Menengai Geothermal Field, albeit with a smaller effect compared to technical, human resource, and logistical risks. The study found that logistical risks significantly influence geothermal drilling project success in the Menengai Geothermal Field, second only to technical risks. The study established that human resource risks significantly influence geothermal drilling project success in the Menengai Geothermal Field. It is recommended that geothermal drilling projects prioritize investment in advanced drilling technologies, predictive geological modeling, and preventive maintenance programs. Geothermal operators should strengthen environmental and safety management by adopting advanced gas detection technologies, enforcing strict blowout prevention measures, and enhancing training on hazard response. It is recommended that geothermal drilling projects adopt integrated logistical systems combining procurement, transport, and storage planning. The study recommends prioritizing comprehensive training programs, retention of skilled personnel, and effective shift scheduling to reduce fatigue.

Keywords: Risk Dynamics, Operational Risk Factors, Technical Risks, Environmental And Safety Risks , Logistical Risks, Human Resource Risks, Performance, Geothermal Drilling Projects.

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1.0 INTRODUCTION

1.1 Background of the Study

Project success is traditionally defined by the “iron triangle” of time, cost, and quality, but modern perspectives incorporate stakeholder satisfaction, sustainability, and long-term impact (Mok et al., 2020; Mirza et al., 2021). Globally, only 35% of projects achieve intended goals, while 16% fail outright, reflecting persistent challenges in aligning strategic intent with execution (PMI, 2023). Operational risks—losses from inadequate processes, systems, people, or external shocks—remain a major determinant of project performance, often causing delays, overruns, and safety failures (Project Management Institute, 2021). In developing countries, weak governance and limited capacity exacerbate these risks (World Bank, 2022), with studies in Kenya showing that only 42% of public projects apply structured risk frameworks (Mwangi & Wekesa, 2023). Literature highlights the importance of integrating digital tools like AI and IoT for predictive monitoring (Agyekum et al., 2022) and adaptive, risk-based management (Zhao & Lee, 2021), yet sector-specific applications in emerging economies remain underexplored. In drilling projects—particularly geothermal—risks stem from technical failures, human error, environmental factors, and systemic inefficiencies, making this phase highly cost-intensive and safety-critical (Sandia National Laboratories, 2022; Deloitte, 2021). Global evidence shows over 60% of drilling projects exceed budgets due to operational risks (IEA, 2022), with advanced economies mitigating through digitalization and regulation, while developing regions face policy gaps, weak institutions, and limited technical capacity (Wang & Liu, 2022; Santos & Rivera, 2023). In Africa, operational risks undermine oil, gas, and geothermal ventures, causing losses from equipment downtime, labor unrest, and governance deficits (NNPC, 2023; Mokoena & Daniels, 2022). East Africa, though rich in geothermal resources, lacks robust risk governance frameworks, leading to poor integration of predictive analytics and weak stakeholder coordination (Agyeman & Kibonde, 2023; Mensah & Tchokponou, 2024). In Kenya, geothermal energy is central to Vision 2030, yet over 25% of drilling delays between 2018–2023 arose from operational failures (GDC, 2023). Reports of 62% non-productive drilling time in Menengai and a 21% cost overrun in Baringo-Silali highlight the magnitude of unmanaged risks (Reuben, 2015; GDC, 2021). Although global frameworks often adapt oil and gas models, they inadequately address geothermal-specific challenges such as extreme heat, fractured formations, and casing demands (Ndiritu et al., 2022; Ochieng & Akinyi, 2021). While predictive analytics and localized risk models offer promise (Mostafavi et al., 2021), their adoption in Kenya is constrained by financial, technical, and policy limitations. Consequently, effective, localized operational risk management tailored to geothermal drilling is critical to improve project success, reduce costs, and attract private investment in Kenya’s energy sector.

1.2 Statement of the Problem

Despite five decades of geothermal development in Kenya, the sector faces significant operational risks that hinder its full potential. Previous studies by GDC (2020) and Reuben (2015) have identified operational risks as major contributors to project delays and cost overruns. However, there is a lack of comprehensive research that specifically examines how operational risks, such as technical challenges, environment and safety concerns, human resource limitations, and logistical issues, affect geothermal drilling project outcomes in Kenya, especially in the Menengai and Baringo-Silali fields. While there are generic risk management frameworks for geothermal drilling, these models are not suited to the specific environmental, technical, and operational conditions in Kenya. As Ndiritu et al. (2022) note, over-reliance on generic oil and gas risk models has led to ineffective mitigation strategies for the unique challenges faced by geothermal drilling projects. Furthermore, the absence of a structured, localized risk assessment framework has resulted in

inefficiencies, as highlighted by Reuben (2015), who noted that operational risks accounted for a significant portion of non-productive time in the Menengai field.

Routine project reviews by the Geothermal Development Company (GDC) consistently identify operational risks as key causes of: 62% non-productive time during drilling operations in Menengai (Reuben, 2015), and 21% cost overruns in the Baringo-Silali Phase I project (GDC, 2021). The consequences of these operational risks go beyond economic costs. They undermine the financial viability of geothermal projects, discourage private investment, and delay Kenya's progress towards meeting its energy goals, as outlined in Kenya's Vision 2030. This study aimed to fill the gap in the existing literature by systematically identifying and quantifying the operational risk factors that affect geothermal drilling in the Menengai field. It assesses the impact of these risks on project success in terms of non-productive time, cost performance, and technical outcomes. Furthermore, this study aimed to develop the first localized risk management framework tailored specifically for geothermal drilling projects in East Africa.

1.3 Objective of the Study

1.3.1 General Objective of the Study

The general objective of the study was to establish the influence of operational risk factors on geothermal drilling project performance in Menengai Geothermal Field in Nakuru County, Kenya.

1.3.2 Specific Objectives of the Study

1. To determine the influence of Technical risks on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya.
2. To assess the influence of environmental and safety risks on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya.
3. To evaluate the influence of Logistical risks on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya.
4. To evaluate the influence of Human resource risks on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya.

1.4 Null Hypotheses of the Study

Ho: Technical risks have no significant influence on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya.

Ho: Environmental and safety risks have no significant influence on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya.

Ho: Logistics risks have no significant influence on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya.

Ho: Human resource risks have no significant influence on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya.

1.5 Scope of the Study

This study is confined to investigating the influence of operational risks on the success of geothermal drilling projects in Kenya, with a specific focus on the Menengai Geothermal Field in Nakuru County, Kenya. The research examined four primary categories of operational risks: technical risks, environmental and safety risks, logistics risks, and human resource risks. These categories were selected based on their frequent occurrence and criticality in geothermal drilling environments. Geographically, the study is limited to one key geothermal field managed by the Geothermal Development Company (GDC), the Menengai Geothermal Field in Nakuru County, Kenya, which is representative of ongoing and large-scale geothermal drilling projects in Kenya. The target population included project managers, engineers, geo-scientists, safety officers, logistics personnel, and human resource practitioners directly involved in these projects. The study period covers drilling projects undertaken from 2018 to the current date, providing a recent and relevant context for analysis. The study does not cover financial, political, or legal risks unless they

intersect with the identified operational risk categories. It also excludes other geothermal fields not actively engaged in drilling operations during the study period. The research findings will therefore be most applicable to public-sector geothermal drilling projects with similar operational settings.

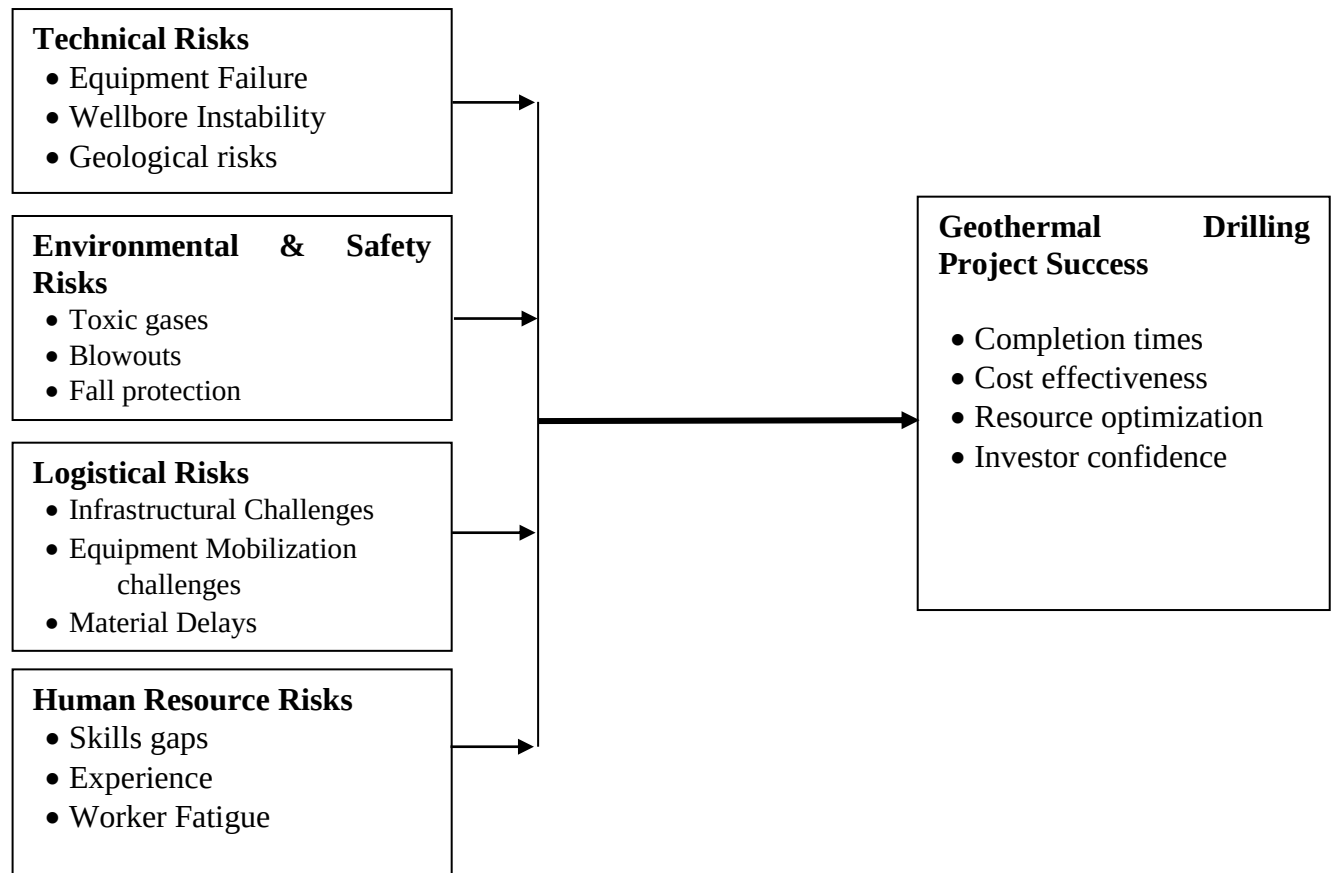
2.0 LITERATURE REVIEW

2.1 Theoretical Review

The theoretical review of this study is anchored on Risk Management Theory and Project Success Theory, which together provide a comprehensive framework for analyzing operational risks and project outcomes in geothermal drilling projects in Kenya. Risk Management Theory, rooted in the works of Knight (1921) and later developed by Bernstein and others, emphasizes systematic identification, assessment, and mitigation of risks, premised on the assumption that risks can be quantified and managed to reduce exposure and enhance project success (Hillson & Murray-Webster, 2017). Its application spans multiple sectors, including energy, where studies show its utility in addressing technical, environmental, and logistical risks that disrupt drilling projects (Radde & Smith, 2018; Gupta & Garg, 2020; Tawfik et al., 2019). In the Kenyan context, geothermal drilling faces risks such as equipment breakdowns, geological uncertainties, hazardous emissions, and labor shortages, all of which threaten cost, safety, and timelines (Ochieng, 2021; Njiru & Mureithi, 2020). While valuable, the theory is critiqued for over-relying on quantitative approaches and neglecting non-quantifiable risks such as political or cultural dynamics (March & Shapira, 1987; Boholm, 2011), underscoring the need for adaptation in dynamic environments. Complementing this is Project Success Theory, which broadens the definition of success beyond the “iron triangle” of time, cost, and scope to include stakeholder satisfaction, sustainability, and long-term benefits (De Wit, 1988; Baccarini, 1999). Shenhar et al. (2001) advanced this multidimensional framework, recognizing that success is subjective and context-specific, shaped by both project execution efficiency and product impact. Empirical applications highlight the interlink between risk management and project outcomes across industries, with proactive risk management shown to improve stakeholder satisfaction, sustainability, and long-term viability (Bannerman, 2008; Kutsch & Hall, 2010; Ofori, 2013). In geothermal projects, Project Success Theory is useful in evaluating how risks influence not only efficiency and output but also community acceptance, environmental compliance, and energy reliability. Critiques note challenges of subjectivity, lack of standardization, and insufficient focus on failure and learning processes (Atkinson, 1999; Ika, 2009; Crawford et al., 2006). Despite these, the theory’s inclusiveness is valuable for high-risk sectors such as geothermal energy, where success is multifaceted and long-term. In Kenya, drilling projects face risks ranging from technical and environmental hazards to logistical delays and labor skill mismatches, which affect both immediate outcomes and broader developmental goals (Ouma & Oloko, 2022). By integrating Risk Management Theory’s structured frameworks with Project Success Theory’s multidimensional perspective, this study can holistically assess how operational risks shape both short-term project delivery and long-term sustainability, making these theories highly relevant for analyzing geothermal drilling projects in the Menengai Geothermal Field and similar contexts

2.2 Conceptual Framework

The conceptual framework below serves as guiding concept in this study.



Independent variables

Dependent variable

Figure 2.1: Conceptual Framework

2.3 Review of the Study Variables

The review of study variables highlights five core dimensions influencing geothermal drilling project success: technical risks, environmental and safety risks, logistical risks, human resource risks, and project success measures. Technical risks encompass equipment failure, wellbore instability, and geological uncertainties, which frequently lead to delays, cost overruns, and safety hazards if inadequately managed; predictive maintenance, geomechanical modeling, and seismic imaging are recommended for mitigation (Mhetre, Konnur & Landage, 2020; Ahmed et al., 2022; Mwangi et al., 2022). Environmental and safety risks include toxic gas emissions such as hydrogen sulfide, blowouts, and fall-related incidents, all of which threaten both ecosystems and worker welfare; real-time monitoring, blowout preventers, and strict fall protection protocols have been emphasized as effective countermeasures (Kundu et al., 2021; Mwangi et al., 2020; Liang & Opoku, 2021). Logistical risks, including infrastructural challenges, delays in equipment mobilization, and material shortages, disrupt project execution and inflate costs, with solutions found in infrastructural planning, supplier coordination, and agile procurement strategies (Adedokun et al., 2021; Gichunge & Mugambi, 2020; Ndungu & Otieno, 2024). Human resource risks, manifested in skills gaps, lack of experience, and worker fatigue, compromise efficiency, safety, and decision-making; these can be mitigated through continuous training, mentorship, and well-being policies that promote adequate rest (Okoth & Ngugi, 2022; Bauer et al., 2021; Pienaar & Venter, 2021). Finally, drilling project success is defined by timely completion, cost-

effectiveness, resource optimization, and sustained investor confidence, with performance evaluated based on adherence to schedules, budgetary discipline, and long-term viability; studies stress that technologies such as real-time monitoring and predictive analytics can improve efficiency and enhance stakeholder trust (Madsen et al., 2021; Johnson & Williams, 2022; Schwartz & Richardson, 2022). Collectively, these variables form a multidimensional framework where unmanaged risks across technical, environmental, logistical, and human domains directly undermine success metrics, while proactive and integrated management enhances efficiency, sustainability, and stakeholder satisfaction. The literature reveals persistent gaps in localized empirical studies, particularly in developing economies such as Kenya, where infrastructural, regulatory, and contextual challenges complicate operational risk management in geothermal drilling projects. This underscores the importance of adopting comprehensive frameworks that simultaneously address technical reliability, safety culture, logistical efficiency, human capital development, and sustainability to ensure project success in high-risk, resource-intensive sectors.

2.4 Empirical Review

The empirical review reveals diverse scholarly efforts to link operational risks with drilling project success across global energy sectors, though significant contextual and empirical gaps remain for geothermal drilling in Kenya. Technical risk studies highlight the importance of addressing equipment failures, geological uncertainties, and wellbore instability. Nurgaliev et al. (2019) in Russia and Krechowicz et al. (2022) in Poland emphasized advanced modeling and risk ranking techniques but limited their scope to oil, gas, or HDD projects. Tufail et al. (2022) in Pakistan stressed proactive planning but neglected external risks, while Okwiri (2017) directly addressed geothermal drilling in Kenya, showing delays and cost overruns caused by well collapse and tool wear but relied heavily on expert opinion, revealing a need for real-time empirical validation. Environmental and safety risks also remain pivotal, with Zeynabi (2024) in Iran stressing adaptive risk profiling and Ogbu et al. (2023) in Nigeria linking pore pressure prediction to blowout prevention. Lebedev and Cherepovitsyn (2024) in Russia highlighted waste management as a neglected environmental determinant, while Deryaev (2024) in Kazakhstan showed how technological innovations reduce safety risks. However, these studies were geographically and sector-specific, lacking transferability to landlocked geothermal projects. Logistical risk studies underscore persistent challenges. Hermawan et al. (2024) in Indonesia identified procurement delays and transport bottlenecks, while Onukwulu et al. (2024) in Nigeria demonstrated supply chain coordination improved delivery efficiency. Similarly, Kalleparambil et al. (2024) highlighted centralized logistics platforms, and Egbumokei et al. (2024) linked contractual clarity to reduced logistical inefficiencies. Yet, all studies remained oil-and-gas-focused and did not address the unique infrastructural and terrain constraints in East Africa's geothermal sector. Human resource risks were consistently shown to undermine drilling efficiency. Rivera (2023) in the U.S. identified fatigue and extended work hours as major risks, while Durrani and Zeeshan (2023) in Pakistan ranked inadequate training and strikes as top contributors to delays. Onyekwere et al. (2024) in the Middle East applied human error frameworks, showing communication and cognitive overload as critical, while Egbumokei et al. (2024) in Sub-Saharan Africa highlighted automation's double-edged effect on safety and skill redundancy. Despite these insights, gaps remain in linking HR risks directly to geothermal-specific outcomes such as drilling timelines and investor confidence. Collectively, the empirical studies provide useful methodological and conceptual foundations, yet most are sector- or region-specific, neglecting Kenya's geothermal context, where technical, environmental, logistical, and HR risks intersect uniquely. This highlights the need for localized, multi-dimensional research that integrates real-time data and contextual realities of geothermal drilling to close knowledge, empirical, and contextual gaps (Okwiri, 2017; Mwangi & Kariuki, 2022).

3.0 RESEARCH METHODOLOGY

The study employed a mixed-methods research design integrating quantitative surveys, qualitative interviews, and document analysis to holistically assess operational risks—technical, environmental and safety, logistical, and human resource—and their impact on geothermal drilling success in Menengai Geothermal Fields, Kenya (Creswell, 2014). The target population comprised 167 stakeholders from the Geothermal Development Company (GDC), including project managers, engineers, geo-scientists, safety officers, logistics personnel, and risk managers (GDC HR Office, 2025). Stratified random sampling was applied to select 116 respondents for the quantitative survey, ensuring representation across professional roles, while purposive sampling identified 17 key informants for qualitative interviews, guided by the principle of data saturation (Hennink & Kaiser, 2022; Morse, 2015). Data collection tools included structured questionnaires with Likert-scale and open-ended items, semi-structured interview guides for senior stakeholders, and secondary data from drilling records, incident logs, and well completion reports. A pilot study with 12 participants tested instrument clarity and reliability, with revisions made based on feedback (Gay, 2009). Validity was ensured through expert review for content validity and factor analysis for construct validity, yielding satisfactory KMO (0.816) and Bartlett's Test results ($p < 0.001$) (Kaiser, 1974). Reliability was assessed using Cronbach's Alpha, with all constructs scoring above 0.70, confirming internal consistency (Sekaran, 2015). Ethical clearance was obtained from JKUAT and NACOSTI, with confidentiality, voluntary participation, and informed consent upheld (Resnik, 2020). Quantitative data were analyzed using SPSS for descriptive and inferential statistics, including correlation and multiple regression analysis, to examine the predictive effect of operational risks on drilling project success (Hair et al., 2005). The regression model used was $Y = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \epsilon$, where Y represented project success and X1–X4 the risk categories. Qualitative data were transcribed and thematically analyzed using NVivo, providing context-specific insights. Triangulation of findings from surveys, interviews, and documents enhanced validity. Additionally, a risk assessment matrix was developed, integrating quantitative frequency-impact scores and qualitative perceptions to categorize risks as low, medium, or high priority, supporting decision-making in geothermal drilling risk management. This methodology ensures comprehensive, reliable, and contextually relevant analysis of operational risks in Kenya's geothermal sector.

4.0 RESEARCH FINDINGS AND DISCUSSIONS

4.1. Response Rate

Table 4.1 shows the response rate of the questionnaires and interview schedules.

Table 4.1: Response Rate

Instruments	Number of Issued/Planned	Number Returned/carried out	Response Rate Percentage (%)
Questionnaires	116	101	87.1%
Interviews	17	12	70.6%

The analysis of Table 4.1 shows a strong overall response rate for both data collection instruments. For the questionnaires, 101 out of the 116 issued were completed and returned, representing a high response rate of 87.1%. This level of participation exceeds the 70% threshold often recommended for survey-based research to ensure adequate representativeness and statistical reliability (Mugenda & Mugenda, 2003). The high return rate suggests that the questionnaire design, delivery method, and follow-up procedures were effective in engaging respondents.

4.2 Descriptive Statistics

This section presents the results of the descriptive statistical analyses of the data and their interpretations. The descriptive statistics helped to develop the basic features of the study and form

the basis of virtually every quantitative analysis of the data. The results were presented in terms of the study objectives.

4.2.1 Technical Risks and Geothermal Drilling Project Success in Nakuru County

The first objective of the study was to determine the influence of Technical risks on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya. This objective was described based on three key constructs: Equipment Failure, Wellbore Instability, and Geological risks.

Table 4.2: Technical Risks and Geothermal Drilling Project Success

Statement	SA %	A %	N %	D %	SD %	Mean	St. Dev
Equipment Failure							
Frequent equipment failure contributes to delays in geothermal drilling project timelines.	18(18)	52(51)	25(25)	5(5)	2(2)	3.77	0.51
The quality of equipment used in geothermal drilling has a significant impact on project success.	14(14)	38(37)	14(14)	23(23)	12(12)	3.18	0.748
Wellbore Instability							
Wellbore instability frequently leads to additional costs and project delays during geothermal drilling operations.	11(11)	55(54)	6(6)	20(20)	9(9)	3.60	0.576
The risk of wellbore instability significantly affects the safety and stability of geothermal projects.	31(31)	50(49)	17(17)	1(1)	0	4.04	0.831
Geological Risks							
Geological uncertainties in the geothermal fields directly influence the success of drilling projects.	17(17)	41(40)	14(14)	8(8)	7(7)	3.61	0.799
Unpredictable geological conditions contribute to drilling inefficiencies and increased operational costs.	26(26)	49(48)	10(10)	9(9)	7(7)	3.76	0.845
Aggregate						3.66	0.7182

The analysis of Table 4.2 indicates that respondents generally perceived technical risks as important determinants of geothermal drilling project success in the Menengai Geothermal Field. Equipment reliability emerged as a notable concern for project success. The statement on frequent equipment failure causing project delays scored high (Mean = 3.77; S.Dev = 0.510), reflecting strong consensus that breakdowns significantly disrupt drilling schedules. While respondents also acknowledged that equipment quality influences project success (Mean = 3.18; S.Dev = 0.748), the slightly lower mean and higher variation suggest mixed experiences with the quality of drilling tools. Collectively, these findings underscore the importance of both preventative maintenance and procurement of high-quality equipment to minimize operational downtime.

Wellbore instability was consistently perceived as one of the most critical technical risks. Its impact on safety and structural stability recorded the highest agreement in the table (Mean = 4.04; S.Dev = 0.831), while its role in causing delays and additional costs was also rated high (Mean = 3.60; S.Dev = 0.576). These results suggest that wellbore stability issues not only affect operational timelines but also have direct implications for worker safety and long-term project viability.

Geological uncertainties and unpredictability were both strongly associated with reduced drilling efficiency and increased costs. Geological uncertainties influencing project success had a mean score of 3.61 (S.Dev = 0.799), while unpredictable geological conditions affecting efficiency and costs scored slightly higher (Mean = 3.76; S.Dev = 0.845). These findings reflect the high operational risk posed by subsurface variability in geothermal projects, highlighting the need for advanced geological surveys and real-time monitoring technologies.

The analysis reveals that structural integrity risks, particularly wellbore instability, are perceived as the most severe technical threat to geothermal drilling success in Menengai, followed closely by equipment-related and geological-related risks. The relatively high aggregate score (Mean = 3.66; S.Dev = 0.7182) across all categories emphasizes the need for integrated technical risk management strategies, combining preventive maintenance, advanced geological assessment, and improved well design to enhance project outcomes.

4.2.2 Environmental and Safety Risks and Geothermal Drilling Project Success in Nakuru

The second objective of the study was to determine the influence of Environmental and Safety Risks on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya. This objective was described based on three key constructs: Toxic gases, Blowouts, and Fall protection.

Table 4.3: Environmental and Safety Risks and Geothermal Drilling Project Success

Statement	SA %	A %	N %	D %	SD %	Mean	St. Dev
Toxic Gases							
The presence of toxic gases during geothermal drilling operations increases the risk of health hazards for workers.	24(24)	53(52)	12(12)	10(10)	2(2)	3.86	0.714
Managing toxic gas emissions effectively is critical for maintaining project timelines and safety.	27(27)	45(44)	13(13)	8(8)	8(8)	3.74	0.995
Blowouts							
Blowouts during drilling operations significantly delay geothermal drilling projects.	26(26)	49(48)	10(10)	9(9)	7(7)	3.76	0.845
Blowout risks are a major safety concern in geothermal drilling and can result in severe environmental damage.	11(11)	55(54)	6(6)	20(20)	9(9)	3.60	0.576
Fall Protection							
Effective fall protection measures reduce the occurrence of accidents and enhance safety during geothermal	19(19)	20(20)	10(10)	46(45)	6(6)	3.01	0.712

drilling.

Insufficient fall protection increases the

risk of worker injuries, negatively 17(17) 41(40) 14(14) 8(8) 7(7) 3.61 0.799

affecting project success.

Aggregate

3.597 0.774

The analysis of Table 4.3 indicates that respondents generally perceived environmental and safety risks as significant determinants of geothermal drilling project success in the Menengai Geothermal Field. Toxic gas hazards emerged as a prominent concern, with the presence of toxic gases increasing health risks for workers scoring high (Mean = 3.86; S.Dev = 0.714). The importance of effectively managing toxic gas emissions to maintain both safety and project timelines was also strongly acknowledged (Mean = 3.74; S.Dev = 0.995). These findings suggest that toxic gas management is considered a critical operational and safety priority in geothermal drilling activities.

Blowouts were also rated highly as an environmental and safety risk. The perception that blowouts significantly delay drilling projects scored a mean of 3.76 (S.Dev = 0.845), while their potential to cause severe environmental damage was rated at 3.60 (S.Dev = 0.576). This reflects a strong awareness of the dual impact of blowouts on both operational efficiency and environmental integrity.

Fall protection measures received moderate agreement compared to subsurface hazards. The risk of insufficient fall protection increasing worker injuries and negatively affecting project success scored a mean of 3.61 (S.Dev = 0.799), whereas the statement that effective fall protection enhances safety was rated lower (Mean = 3.01; S.Dev = 0.712). This suggests that while fall-related risks are recognized, they may not be viewed with the same urgency as subsurface safety threats.

The analysis reveals that toxic gas hazards are perceived as the most pressing environmental and safety risk, followed closely by blowouts, with fall protection ranking lower in perceived criticality. The aggregate score (Mean = 3.597; S.Dev = 0.774) underscores the need for comprehensive environmental and safety risk management strategies, with particular focus on subsurface hazard prevention and mitigation, while also ensuring adequate attention to surface-level safety measures such as fall protection.

Environmental and safety risks were also perceived as critical in determining geothermal drilling outcomes. The presence of toxic gases as a health hazard and the importance of managing emissions effectively strongly align with Mutua & Wanjiru (2023), who linked inadequate hazardous gas controls to both health risks and project delays.

Blowouts were similarly acknowledged as a significant safety concern, with delays caused by such incidents scoring 3.76 (S.Dev = 0.845) and environmental damage risk scoring 3.60 (S.Dev = 0.576). These figures corroborate Odhiambo (2024), who emphasized blowouts' potential for catastrophic safety and environmental consequences. Fall protection measures, while recognized as important for insufficient protection increasing injury risk, had mixed perceptions regarding their effectiveness in reducing accidents. This partially supports Mwangi & Kimani (2021), who argued that while safety gear reduces accident rates, its impact depends heavily on consistent compliance and training. Overall, these results affirm the literature's consensus that environmental hazard control and proactive safety planning are fundamental to geothermal project success.

4.2.3 Logistical Risks and Geothermal Drilling Project Success in Nakuru County

The third objective of the study was to determine the influence of Environmental and Safety Risks on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya. This objective was described based on three key constructs: Infrastructural Challenges, Equipment

Mobilization, and Material Delays.

Table 4.4: Logistical Risks and Geothermal Drilling Project Success

Statement	SA %	A %	N %	D %	SD %	Mean	St. Dev
Infrastructure Challenges							
Poor road conditions and site accessibility significantly delay drilling operations in Menengai.	29(29)	49(48)	13(13)	8(8)	2(2)	3.95	0.820
Limited on-site support facilities (storage yards, workshops, housing) negatively impact project performance.	24(24)	53(52)	12(12)	10(10)	2(2)	3.86	0.714
Equipment Mobilization Challenges							
Delays in transporting heavy drilling equipment to the Menengai field affect project timelines.	6(6)	46(45)	27(27)	15(15)	7(7)	3.28	0.834
Inadequate handling equipment (e.g., cranes, trucks) during mobilization increases the risk of operational delays.	24(24)	39(38)	14(14)	11(11)	16(16)	3.40	0.925
Material Delays							
Shortages or late delivery of drilling materials (e.g., casings, cement, drilling mud) disrupt drilling progress.	31(31)	47(46)	15(15)	8(8)	0	4.00	0.621
Inefficient procurement and supply chain processes contribute to material delays in geothermal drilling projects.	26(26)	42(41)	16(16)	11(11)	6(6)	3.71	0.847
Aggregate						3.70	0.794

The analysis of Table 4.4 indicates that respondents generally viewed logistical risks as critical determinants of geothermal drilling project success in the Menengai Geothermal Field. Logistics-related challenges in road conditions and site accessibility were rated highly (Mean = 3.95; S.Dev = 0.820), reflecting a strong perception that good road conditions and site accessibility is essential to prevent operational disruptions. Similarly, limited on site facilities scored a mean of 3.86 (S.Dev = 0.714), highlighting the potential for significant project setbacks if such facilities are not adequate at the project sites. Equipment mobilization challenges received moderate ratings compared to infrastructural challenges. The perception that delays in transporting heavy drilling equipment to the Menengai field affect project timelines scored 3.28 (S.Dev = 0.834), while Inadequate handling equipment (e.g., cranes, trucks) during mobilization increases the risk of operational delays was rated slightly higher at 3.40 (S.Dev = 0.925). These moderate means suggest that while equipment mobilization are recognized as important, they may be viewed as less pressing compared to infrastructural logistical risks.

Material delays emerged as a particularly critical logistical concern. Shortages or late delivery of

drilling materials (e.g., casings, cement, drilling mud) disruption to drilling progress scored the highest mean in the table (Mean = 4.00; S.Dev = 0.621), indicating strong consensus on its role in preventing delays and reducing logistical risks. Inefficient procurement and supply chain processes contribution to material delays in geothermal drilling projects also scored highly (Mean = 3.71; S.Dev = 0.847), reinforcing the importance of proactive logistics management.

Overall, the results suggest that infrastructural challenges and materials delays are perceived as the most influential logistical factors in ensuring geothermal drilling project success in Menengai. The aggregate score (Mean = 3.70; S.Dev = 0.794) emphasizes the necessity for robust logistical planning systems that address both material management and provision of attendant infrastructure to minimize delays and enhance operational efficiency.

4.2.4 Human Resource Risks and Geothermal Drilling Project Success in Nakuru County

The fourth objective of the study was to determine the influence of Human Resource Risks on Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya. This objective was described based on three key constructs: Skills gaps, Experience, and Worker Fatigue.

Table 4.5: Human Resource Risks and Geothermal Drilling Project Success

Statement	SA %	A %	N %	D %	SD %	Mean	St. Dev
Skills Gaps							
Gaps in the technical skills of the workforce contribute to delays and inefficiencies in geothermal drilling projects.	27(27)	45(44)	13(13)	8(8)	8(8)	3.74	0.995
Training programs to bridge skills gaps are essential for improving the overall success of geothermal drilling operations.	26(26)	42(41)	16(16)	11(11)	6(6)	3.71	0.847
Experience							
Lack of experienced personnel increases the likelihood of errors and inefficiencies in geothermal drilling projects.	23(23)	44(43)	14(14)	11(11)	9(9)	3.38	0.774
Experienced workers contribute significantly to minimizing risks and enhancing the success of geothermal drilling projects.	18(18)	52(51)	25(25)	5(5)	2(2)	3.81	0.510
Worker Fatigue							
Worker fatigue due to long shifts significantly affects the safety and productivity of geothermal drilling operations.	29(29)	49(48)	13(13)	8(8)	2(2)	3.95	0.820
Reducing worker fatigue through better shift management improves the overall performance of geothermal drilling projects.	31(31)	50(49)	17(17)	1(1)	0	4.04	0.831
Aggregate						3.772	0.796

The analysis of Table 4.5 indicates that respondents generally regarded human resource risks as significant determinants of geothermal drilling project success in the Menengai Geothermal Field. Skills-related risks were rated highly, with gaps in technical skills contributing to delays and inefficiencies scoring a mean of 3.74 (S.Dev = 0.995). Similarly, the necessity of training programs to bridge such gaps recorded a mean of 3.71 (S.Dev = 0.847), highlighting the importance placed on continuous workforce development to ensure operational efficiency.

Experience levels among personnel also emerged as a critical factor. The lack of experienced workers was associated with increased errors and inefficiencies (Mean = 3.38; S.Dev = 0.774), while the contribution of experienced personnel to risk minimization and project success was rated even higher (Mean = 3.81; S.Dev = 0.510). These results underscore the value of retaining and deploying seasoned workers in technically demanding geothermal drilling environments.

Worker fatigue was perceived as one of the most pressing human resource risks. Fatigue due to long shifts scored 3.95 (S.Dev = 0.820), and the role of improved shift management in enhancing project performance recorded the highest mean in the table (Mean = 4.04; S.Dev = 0.831). These findings point to strong consensus that managing workload and rest periods is essential for both safety and productivity.

The relatively high aggregate score for the category (Mean = 3.772; S.Dev = 0.796) reflects a shared recognition among respondents that human resource factors, especially skill levels, experience, and fatigue management, are central to minimizing operational risks and ensuring successful geothermal drilling outcomes in Menengai.

The findings on human resource risks in the Menengai Geothermal Field are largely consistent with the broader literature on geothermal drilling and energy-sector project management. Skill gaps and inadequate training have been repeatedly identified as major contributors to inefficiency and operational delays in geothermal drilling projects (DiPippo, 2016; World Bank, 2020). Similar to the present study's results, IRENA (2021) emphasizes that comprehensive and continuous training programs—particularly those tailored to site-specific geological and technical conditions—are essential to improving performance outcomes. The high rating given to the importance of experienced personnel aligns with research by Chamorro et al. (2018), which found that experience in geothermal drilling significantly reduces non-productive time by improving decision-making under uncertainty.

4.2.5 Geothermal Drilling Project Success in Menengai Nakuru County

Finally, the study sought to determine the status of the Geothermal Drilling Project Success in Menengai Geothermal Field in Nakuru County, Kenya. This was the dependent variable and the status of this variable was described in terms of; Completion times, Cost effectiveness, Resource optimization, and Investor confidence.

Table 4.6: Geothermal Drilling Project Success

Statement	SA %	A %	N %	D %	SD %	Mean	St. Dev
Completion Times							
Delays in geothermal drilling operations frequently result in the failure to meet project deadlines.	11(11)	55(54)	6(6)	20(20)	9(9)	3.60	0.576
Timely completion of geothermal drilling projects is essential for ensuring investor confidence and project success.	23(23)	44(43)	14(14)	11(11)	9(9)	3.38	0.774

Cost Effectiveness

The efficient management of costs is crucial to the financial success of geothermal drilling projects.

18(18) 52(51) 25(25) 5(5) 2(2) 3.81 0.510

Cost overruns are a major obstacle to achieving profitability and long-term sustainability in geothermal drilling projects.

11(11) 52(51) 20(20) 12(12) 7(7) 3.47 0.814

Resource Optimization

Effective resource allocation (e.g., equipment, manpower) significantly improves the efficiency and success of geothermal drilling projects.

5(5) 43(43) 43(43) 9(9) 1(1) 3.43 0.764

Proper utilization of resources reduces waste and enhances the overall performance of geothermal drilling projects.

11(11) 59(58) 13(13) 13(13) 5(5) 3.57 1.009

Investor Confidence

Ensuring project milestones are met within budget and on time is crucial for maintaining investor confidence in geothermal drilling projects.

6(6) 46(45) 27(27) 15(15) 7(7) 3.28 0.834

A strong track record of successful geothermal drilling projects increases the likelihood of attracting future investment.

24(24) 39(38) 14(14) 11(11) 16(16) 3.40 0.925

Aggregate

3.49 0.776

The findings in Table 4.6 reveal that geothermal drilling project success in the Menengai Geothermal Field is influenced by a combination of time performance, cost control, resource management, and the ability to sustain investor confidence. Completion times emerged as a notable concern, with delays being widely recognized as a threat to meeting project deadlines (Mean = 3.60; S.Dev = 0.576). The emphasis placed on timely completion as a determinant of investor trust (Mean = 3.38; S.Dev = 0.774) reflects an understanding that schedule adherence is not only an operational necessity but also a reputational factor for future investment opportunities.

Cost effectiveness recorded some of the highest mean scores in the table, with efficient cost management ranked particularly high (Mean = 3.81; S.Dev = 0.510), reinforcing its central role in project sustainability. Concerns about cost overruns (Mean = 3.47; S.Dev = 0.814) further underline the need for robust financial controls in geothermal drilling operations.

The findings also highlight the significance of resource optimization, where effective allocation of manpower and equipment scored moderately (Mean = 3.43; S.Dev = 0.764), while proper utilization to reduce waste scored slightly higher (Mean = 3.57; S.Dev = 1.009). These results suggest that while the concept of resource efficiency is widely valued, practical constraints may

limit its consistent application. Finally, investor confidence indicators registered the lowest mean scores compared to other factors, with meeting milestones within budget and on time (Mean = 3.28; S.Dev = 0.834) and leveraging past project success for future investment (Mean = 3.40; S.Dev = 0.925) both receiving only moderate agreement. This suggests that stakeholders may perceive investor confidence as an outcome shaped by other operational dimensions—particularly time and cost performance—rather than as a directly managed factor.

Collectively, the results indicate that strengthening geothermal drilling project success in Menengai requires an integrated approach that prioritizes cost control, timely completion, efficient resource use, and the deliberate cultivation of a positive track record to enhance investor trust. The overall aggregate score (Mean = 3.49; S.Dev = 0.776) reflects a generally positive outlook but also signals room for improvement across all four dimensions.

4.4 Inferential Statistics

Multivariate regression analysis was used to determine the multiple regression model hypothesized in chapter three held. It was also used to determine how the independent variables influenced the dependent variable collectively. The analysis was also meant to establish the extent to which each independent variable affected the dependent variable in such a collective set up and which were the more significant factors. The results are summarized in Table 4.7.

Table 4.7: Multiple Regression Analysis Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.701	0.491401	0.448354	3.172921

a. Dependent Variable: Geothermal Drilling Project Success in Menengai, Nakuru County

b. Predictors: (Constant), Technical Risks, Environmental & Safety Risks, Logistical Risks, Human Resource Risks

The regression analysis in Table 4.7 shows that the relationship between the dependent variable (geothermal drilling project success) and all the independent variables (technical risks, environmental and safety risks, logistical risks, and human resource risks) pooled together had a model correlation coefficient (R) = 0.701. The adjusted R-square (R^2_{Adj} = 0.448) indicates that the model could explain up to 44.8% of the variations in geothermal drilling project success in the Menengai Geothermal Field, Nakuru County. This proportion suggests a moderately strong explanatory power of the model. However, it also implies that 55.2% of the variations are attributable to other factors not included in the model, suggesting that incorporating additional predictive variables could enhance the model's accuracy.

Field et al., (2011) also state that the appropriateness of the multiple regression model as a whole can be tested using F test. Therefore, the study also performed an ANOVA on the independent and dependent variables and the results are summarized in Table 4.10.

Table 4.8: Summary of ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	387.74	4	96.934	9.840349	.000 ^b
Residual	945.66	96	9.850667		
Total	1333.40	100			

a. Dependent Variable: Geothermal Drilling Project Success in Menengai, Nakuru County

b. Predictors: (Constant), Technical Risks, Environmental & Safety Risks, Logistical Risks, Human Resource Risks

The ANOVA results in Table 4.8 indicate that the regression model was statistically significant in predicting geothermal drilling project success in the Menengai Geothermal Field, Nakuru County,

$F(4, 96) = 9.840, p < 0.001$. This means that, collectively, technical risks, environmental and safety risks, logistical risks, and human resource risks significantly contributed to explaining variations in drilling success. The significance value of 0.000, which is less than the conventional alpha level of 0.05, confirms that the regression model provides a better fit to the data than a model without these predictors. This finding confirms that the model predicted by Table 4.9 and shows it is indeed a fitting model. Therefore, the model is appropriate for assessing the influence of these risk factors on geothermal drilling project outcomes.

In order to determine which of the operations risk factors was the most influential on geothermal drilling project success in Menengai Geothermal Field in Nakuru County, Kenya, the beta value was used. The results are given in Table 4.9 provides a summary of the multiple linear regression analysis correlation coefficients.

Table 4.2: Summary of Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	14.21	3.759		3.7803	0.001
Technical Risks	0.563	0.108	0.455	5.2140	0.000
Environmental & Safety Risks	0.176	0.083	0.162	2.1084	0.032
Logistical Risks	0.443	0.084	0.407	5.2857	0.000
Human Resource Risks	0.357	0.117	0.278	3.0598	0.000

a. Dependent Variable: Geothermal Drilling Project Success in Menengai, Nakuru County

The constant term ($B = 14.21, p = 0.001$) represents the baseline value of geothermal drilling project success when all the predictors—technical risks, environmental and safety risks, logistical risks, and human resource risks—are held at zero. This means that, in the absence of any measurable influence from these risk factors, the model predicts an average project success score of 14.21 units. While this is a theoretical scenario unlikely to occur in practice, it establishes the starting point from which each predictor's effect is measured. The positive constant indicates that other unmeasured factors also contribute positively to drilling success.

The unstandardized coefficient for technical risks ($B = 0.563, p < 0.001$) indicates that for every one-unit improvement in managing technical risks, geothermal drilling project success is predicted to increase by 0.563 units, holding all other factors constant. This makes technical risks the most influential predictor in the model ($\beta = 0.455$). The implication is that reducing uncertainties related to drilling technology, geological assessments, and equipment reliability could yield substantial performance gains. These results align with the correlation findings and reinforce the need for investment in advanced drilling technologies, predictive modeling, and preventative maintenance strategies to ensure operational continuity.

The unstandardized coefficient for environmental and safety risks ($B = 0.176, p = 0.032$) means that a one-unit improvement in the management of environmental and safety risks is associated with a 0.176-unit increase in drilling project success, assuming other predictors remain constant. While statistically significant, this is the smallest effect size among the predictors ($\beta = 0.162$). This suggests that, although safety protocols and environmental safeguards are crucial for compliance and hazard prevention, their measurable impact on performance is less pronounced than technical, logistical, or human resource factors in this context. However, the significance value below 0.05 underscores that even modest improvements here contribute meaningfully to overall success.

The unstandardized coefficient for logistical risks ($B = 0.443, p < 0.001$) indicates that a one-unit improvement in logistical efficiency—such as timely delivery of materials, improved site access,

and coordinated scheduling—predicts a 0.443-unit increase in drilling project success, holding other factors constant. This is the second most influential predictor in the model ($\beta = 0.407$), highlighting that logistical planning is a major determinant of timely and cost-effective operations. Efficient logistics mitigate costly delays and resource shortages, which can otherwise escalate project costs and extend completion timelines. The high statistical significance emphasizes that logistical optimization is a critical area for intervention.

The unstandardized coefficient for human resource risks ($B = 0.357$, $p < 0.001$) shows that each one-unit improvement in human resource capacity and management predicts a 0.357-unit increase in drilling project success, when all other predictors are held constant. This makes it the third most influential factor ($\beta = 0.278$). Skilled personnel, adequate staffing levels, and effective leadership directly enhance operational efficiency, safety, and problem-solving capacity in complex drilling environments. Given the statistical significance at the 0.001 level, targeted investments in training, recruitment, and workforce retention strategies are likely to translate into measurable gains in project performance

5.0 CONCLUSIONS, AND RECOMMENDATIONS

5.1 Conclusion

The study establishes that technical risks—particularly equipment failures, wellbore instability, and geological uncertainties—are significant determinants of geothermal drilling project success in the Menengai Geothermal Field. Regression results confirm that effective management of these risks substantially enhances project outcomes, making technical risks the most influential predictor in the model. Frequent equipment breakdowns, structural instability, and unpredictable geological conditions not only cause delays but also elevate operational costs and safety concerns. These findings underscore the need for integrated technical risk mitigation strategies combining advanced geological assessments, modern drilling technology, and robust preventive maintenance to safeguard operational continuity and ensure sustainable project performance.

The findings establish that environmental and safety risks significantly influence geothermal drilling project success in the Menengai Geothermal Field, albeit with a smaller effect compared to technical, human resource, and logistical risks. Hazard prevention—particularly management of toxic gases and blowout risks—emerged as critical for minimizing operational disruptions and ensuring compliance. While advancements in detection systems and protective protocols have reduced some risks, gaps remain in managing subsurface hazards and extreme weather impacts. This study reinforces the importance of integrating robust environmental safeguards and safety practices into drilling operations, as their proactive management directly enhances operational efficiency, protects worker health, and sustains project timelines in Kenya's geothermal sector.

The study establishes that logistical risks significantly influence geothermal drilling project success in the Menengai Geothermal Field, second only to technical risks. Inefficiencies in equipment delivery, transportation of materials, and infrastructure challenges—poor roads conditions and materials transportation—were found to disrupt operations, and delay project timelines. Effective logistical management emerged as a critical enabler of operational efficiency. The findings emphasize that addressing logistical bottlenecks not only minimizes downtime but also enhances overall project performance. A proactive, well-coordinated, and is therefore essential for meeting Kenya's geothermal development goals and ensuring sustainable, timely, and safe drilling operations.

The study established that human resource risks significantly influence geothermal drilling project success in the Menengai Geothermal Field. Skills gaps, limited experience among personnel, and worker fatigue were identified as the most critical threats, with each capable of undermining operational efficiency, safety, and timely delivery. Regression analysis confirmed a strong, positive relationship between effective human resource risk management and improved project

outcomes. Qualitative evidence reinforced that retaining experienced staff, enhancing training programs, and managing workloads are vital to sustaining high performance. Addressing these risks through strategic workforce planning ensures operational continuity, strengthens safety compliance, and boosts productivity, making human resource management a decisive factor in geothermal drilling success.

5.2 Recommendations of the Study

The study makes the following recommendations based on the findings;

It is recommended that geothermal drilling projects prioritize investment in advanced drilling technologies, predictive geological modeling, and preventive maintenance programs. Strengthening equipment reliability, improving well design, and deploying real-time monitoring systems will reduce downtime, enhance safety, and optimize resource utilization, thereby significantly improving the overall success rate of geothermal drilling operations in the Menengai Geothermal Field. Geothermal operators should strengthen environmental and safety management by adopting advanced gas detection technologies, enforcing strict blowout prevention measures, and enhancing training on hazard response. Integrating these measures into routine operations will not only safeguard personnel and the environment but also improve efficiency and ensure timely project delivery. It is recommended that geothermal drilling projects adopt integrated logistical systems combining procurement, transport, and on site material storage facilities planning. Investment in real-time tracking, supplier reliability audits, and provision of infrastructure will strengthen operational efficiency, reduce delays, and ultimately improving project outcomes in Kenya's geothermal sector. The study recommends prioritizing comprehensive training programs, retention of skilled personnel, and effective shift scheduling to reduce fatigue. Additionally, structured mentorship and targeted recruitment should be implemented to bridge skills gaps, ensuring a competent and motivated workforce capable of sustaining operational efficiency and delivering successful geothermal drilling outcomes in Nakuru County.

5.3 Areas for Further Research

Based on the above concluded study, empirical gaps emerged that need to be addressed in future studies, therefore, the following studies are recommended for future research;

- 1. Technical Risks** – Future research could examine the immediate impact of emerging geothermal drilling technologies—such as automated wellbore stabilization tools, AI-based geological modeling, and improved directional drilling software—on downtime reduction and drilling efficiency in active Kenyan geothermal fields.
- 2. Environmental and Safety Risks** – A focused study could assess the effectiveness of enhanced safety protocols (e.g., upgraded personal protective equipment, real-time gas detection, and emergency blowout prevention systems) in reducing incident rates during active drilling operations.
- 3. Logistical Risks** – Researchers could evaluate how integrated digital supply chain platforms—offering real-time tracking, predictive procurement, and infrastructure development affect drilling timelines, budget control, and equipment availability.
- 4. Human Resource Risks** – Future studies could investigate the short-term outcomes of targeted skills training and fatigue management programs, measuring their effect on productivity, compliance with safety standards, and task completion rates within a single project phase.

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