FROM ASSUMPTION TO ACCURACY: HOW GEOTECHNICAL INVESTIGATIONS TRANSFORMED RESOURCE EXPLORATION ECONOMICS

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Abstract

In resource-rich yet technologically constrained regions of the developing world, natural resource exploration often relies on rule-of-thumb probabilities of success due to limited access to modern geophysical technologies. This practice introduces significant uncertainty into the economic evaluation of exploration ventures, potentially leading to suboptimal investment decisions. This study presents an economic analysis of a proposed oil exploration project in an already explored hydrocarbon belt in Pakistan. Initially, the expected monetary value (EMV) was calculated using a conventional 20% probability of success, with an estimated reserve of 100 million barrels and an exploration cost of USD 20 million. The breakeven probability of success was derived based on net present value (NPV) analysis. Subsequent geotechnical investigations utilising advanced geophysical equipment revealed a more favourable subsurface structure, increasing the estimated probability of success to 50%. The revised economic model demonstrated a substantially improved breakeven outlook and reduced project risk. This case highlights the critical role of modern technology in enhancing the accuracy of geological data and reducing uncertainty in economic assessments. The findings offer broad applicability for de-risking strategies in resource exploration, as well as in the evaluation of other high-investment projects under uncertainty.

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1.0 INTRODUCTION

The exploration of natural resources is inherently a high-risk endeavour, characterised by significant variability in outcomes; discoveries may exceed expectations, fall short, or yield no reserves at all. Due to the inability to examine subsurface geological formations with certainty, initial estimates, particularly for oil reserves, are typically conservative. This uncertainty renders oil exploration projects especially risky and economically complex. To mitigate potential losses, profit margins are often structured to be sufficiently large to absorb failures, further complicating economic evaluations. The economic analysis of such projects generally depends on technical data provided by geological and exploration experts; however, if these data are ambiguous or incomplete, the resulting projections may be flawed. Therefore, accurate interpretation of geological characteristics is essential to ensure the reliability of any economic assessment, as the high degree of uncertainty and risk creates a classic Catch-22 scenario for stakeholders.

This paper presents an economic analysis of an oil exploration site located in the Khyber Pakhtunkhwa Province of Pakistan. The study area, part of a hydrocarbon-rich belt, has previously been explored by several companies. Initially, an expected monetary value (EMV) analysis was conducted based on a rule-of-thumb approach commonly used in the region. However, the author emphasised the need for geotechnical investigations using modern technology to validate the subsurface geological structure. Consequently, advanced geotechnical investigations were undertaken, revealing that the reservoir was significantly larger and richer than previously estimated. As a result, the economic analysis was revised to reflect the new findings. The outcomes of the analysis before and after the geotechnical investigations differed substantially, underscoring the importance of accurate geological data in economic evaluations of exploration projects. The core objective of this paper is to validate how use of modern geophysical equipment improved the economic analysis process compared to reliance on rule of thumb. When curtain of uncertainty was removed by geotechnical investigations, economic worth of exploration venture was estimated more precisely. It is interesting to mention that the study presented in this paper has global applicability as it is illustrative of the improvements that can be made in risk assessment and cost savings that can be achieved as a result of technical investigations prior to full exploration of a site, product, program, policy or other intended investment ventures. For instance, if site selection for development of a commercial market is intended then economic analysis should follow a well-articulated technical analysis using modern equipment and mapping software (Ali and Gul, 2011).

This study is organised into ten concise sections. Following the introduction in Section 1, a comprehensive literature review is presented in Section 2, with a particular focus on the importance of geotechnical investigations in investment initiatives, including applications across various fields and disciplines. Section 3 outlines the key characteristics of the research area, while Section 4 presents the conceptual framework of the study, which centres on the critical issue of accurately estimating the expected monetary value (EMV) of natural resource exploration projects. Section 5 describes the research methodology, which involved field visits, interviews, and discussions with hydrocarbon experts, investors, geologists, and technical executives. Section 6 details the initial economic analysis conducted prior to geotechnical investigations, which provided an unclear assessment and highlighted the need for a more thorough investigation of the reservoir's structure and size. Section 7 presents the geotechnical investigations, including a description of the equipment and techniques used. Section 8 explains the revised economic analysis carried out after the geotechnical investigations, which yielded a much clearer understanding of the site and informed executive decision-making regarding exploration. Section 9 compares the analytical results before and after the geotechnical investigations. Finally, Section 10 presents the study's conclusions and offers policy recommendations for the exploration of natural resource projects.

2.0 LITERATURE REVIEW

Researchers have consistently emphasised the critical importance of using modern geotechnical equipment and analytical techniques to accurately evaluate geological strata and subsurface reservoir structures in natural resource exploration projects. These technological tools not only improve the precision of geological interpretations but also reduce the uncertainty associated with estimating resource potential. Concurrently, a significant body of literature addresses the economic analysis of exploration ventures, with a specific focus on the complexities introduced by intrinsic geological and market-related risks. Numerous interrelated factors, ranging from structural geology and reservoir continuity to financial volatility and regulatory conditions, influence the probability of success in oil and gas exploration projects. Consequently, it becomes imperative to conduct a comprehensive assessment of all constituent elements of risk and uncertainty prior to initiating exploration activities. To provide contextual clarity and demonstrate alignment with the current study, several key contributions from recent research are discussed in the following sections.

The economic viability of oil and gas exploration projects is inherently uncertain due to geological unpredictability and high upfront investment risks. Recent literature increasingly emphasises the role of modern geotechnical tools, data analytics, and simulation methods in improving accuracy in subsurface assessments and enhancing decision-making. Modern geophysical tools have significantly improved the precision of subsurface imaging and reservoir characterisation. Ali and Gul (2011) underscore the transformative role of advanced geophysical equipment in geotechnical site characterisation, especially for detecting structural features deep below. Similarly, Lutenegger (2019) outlines the importance of detailed site investigations in reducing subsurface uncertainty, a key step before large capital deployment. These points are echoed by Hanaei *et al.* (2020), who show how the presence of hydrocarbon contamination affects the geotechnical properties of soils, further justifying the need for refined testing. Bui *et al.* (2024) and Fathi *et al.* (2023) present innovations in reservoir characterisation using numerical modelling and full-waveform inversion, respectively, to build three-dimensional models of reservoir properties. These technical improvements help mitigate risk by enhancing understanding of the stratigraphic structure and reservoir productivity. Gopalakrishnan (2022) shows that modern exploration methods have a significant impact on reserves-to-production ratios, especially when integrated with AI-based assessments, as also supported by Li *et al.* (2025) in fractured reservoir studies.

There has been growing use of machine learning (ML) to evaluate and interpret subsurface data, thereby reducing uncertainty in hydrocarbon exploration. Anees *et al.* (2022) utilised ML alongside petrophysical data to evaluate hydrocarbon potential, showing a clear link between technological integration and improved predictive accuracy. Similarly, Roustazadeh *et al.* (2022) and Makhotin *et al.* (2020) demonstrated ML's capacity to estimate recovery factors and de-risk asset evaluation. Xie *et al.* (2023) applied ML in assessing tectonic fracture development and its influence on reservoir output, providing crucial insight into productivity forecasts. Ashraf *et al.* (2019) and Discover Geoscience (2024) combine well-log data with 3D seismic interpretation to classify reservoir facies, illustrating how integration of seismic data and machine learning results in clearer structural insights. These findings align with the conclusions of Schenk and Pollastro (2024), who advocate for analogue-based estimation techniques that help in anticipating the yield of unexplored regions.

Economic evaluation of exploration projects is a complex process due to the stochastic nature of geological outcomes. Brealey *et al.* (2018) and White *et al.* (2020) provide fundamental principles of engineering economic analysis, particularly relevant for cost-benefit assessments under risk. Ibarra *et al.* (2017) explored the concept of "value of information" in exploration projects, highlighting how investment in better geological data directly correlates with improved project valuation. Lerche (2019) provides a detailed critique of economic risking techniques used in hydrocarbon exploration, underlining the inadequacies in models that ignore geological variability. Ren *et al.* (2022) proposed an integrated economic model to evaluate offshore oil projects under uncertainty, demonstrating how probabilistic simulations and cash flow models can improve investor decision-making. This is reinforced by Bickley and Michel (2018), who linked hazard risk modelling with insurance pricing—highlighting how risk is transferred and absorbed financially in exploration ventures. Domingues (2019) reviews traditional and modern prospection techniques, pointing out that accurate geological diagnosis is the starting point of any viable economic forecast.

Multiple studies address the unique geological and policy landscape of Pakistan's hydrocarbon sector. Ali *et al.* (2021) applied the discounted cash flow model to evaluate shale gas potential in Pakistan, revealing how resource valuation varies dramatically with geological certainty. Hussain *et al.* (2024) and Qadri *et al.* (2022) used rock physics modelling and petrophysical characterisation, respectively, to assess reservoir quality in the Indus Basin. Tahir *et al.* (2024) and Usman and Shah (2023) provide comprehensive evaluations of shale gas and broader hydrocarbon exploration trends in Pakistan, touching on technical, regulatory, and policy-level bottlenecks. Syed Haider Ali (2024) assessed Pakistan's reservoir potential through a strategic lens, asserting that significant untapped resources remain underexplored due to poor structural diagnostics and limited integration of modern geotechnical tools. Chittumuri *et al.* (2025) emphasised the importance of GIS and ML-based risk analytics for oil pipeline failures, adding relevance for downstream considerations.

The reviewed literature consistently emphasises that oil and gas exploration is fraught with geological, technical, and financial uncertainties. However, these challenges can be partially mitigated through the adoption of advanced geotechnical investigations, seismic imaging, and machine learning algorithms. Accurate site characterisation not only improves the quality of economic forecasts but also helps investors manage risk. In Pakistan's context, the integration of modern technologies in the exploration process remains limited but is gaining traction. Studies specific to the region support the premise of the current research: that revised economic analysis based on modern geotechnical findings offers a more realistic and reliable basis for investment decisions in hydrocarbon ventures. This reinforces the need for up-to-date, data-driven, and site-specific evaluations before launching exploration operations.

3.0 CONCEPTUAL FRAMEWORK

From a conceptual standpoint, an in-depth understanding of available exploration options is the first essential step in the economic analysis process. At this stage, technical details of the exploration alternatives are shared with economic and financial analysts. To ensure accurate interpretation of geological data, geotechnical and geological experts collaborate closely with the economic analysis team. The risks and uncertainties associated with each exploration option are thoroughly assessed based on detailed geological evaluations. This risk assessment is critical, as the economic viability of each option must account for potential uncertainties. Following a comprehensive analysis, the most suitable option is recommended for implementation. However, prior to execution, the potential consequences of the proposed decision are evaluated and communicated to the executive team. This structured approach to economic analysis in hydrocarbon exploration projects is illustrated in Figure 1.

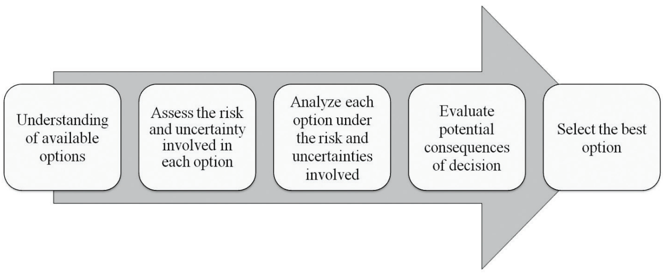

Figure 1: Steps of decision-making process in case of investment ventures

The central challenge in exploration projects lies in the accurate estimation of the project's Expected Monetary Value (EMV). Mathematically, EMV is defined as the product of the probability of occurrence of a given event and the corresponding profit or loss if that event occurs. Therefore, calculating EMV requires two key inputs: the probability of an event and the financial impact associated with its occurrence. However, in the context of exploration projects, it is also essential to account for the value of risk capital to cover potential expenditures arising from various contingencies. In this study, the Expected Monetary Value was calculated using Equation 1.

Expected monetary value (EMV) $= [(r \times \lambda_s) - \{r_c\,(1 - \lambda_s)\}]$ (1)

Where 'r' is monetary reward, 'λ_s' is probability of success assigned to project on basis of geological details and 'r_c' is risk capital which accounts for cost of exploration, dry hole charges, failures and other expenditures.

For exploration projects, probability of success 'λ_s' has typical values based on geotechnical and geological details of strata under exploration and previous history of exploration in the area. These values are shown in Table 1.

Table 1: Probability of success in case of exploration project (Source: Author's own work based on records of exploration in research area)

Probability of Success (λ_s)	Interpretation
0.5	Probability of success of a highly explored area with record of previous explorations and geological structures confirmed by fresh site investigations
0.2-0.49	Probability of success for moderately explored area
0.1-0.19	Probability of success on a new location in a slightly explored area
0.01-0.09	Probability of success in unexplored area or a new location

The research area had a prior history of oil exploration, having been previously examined by multiple oil exploration companies. Consequently, it was categorised as a moderately explored zone. Historically, these companies employed a standard probability of success value of 0.2 (or 20%) for economic analyses, based on convention rather than empirical verification through geotechnical investigations. This figure had effectively become a rule of thumb. Accordingly, for the initial economic assessment in this study, a probability of success value of 0.2 was adopted, as shown in Table 1. However, it was recommended that advanced geotechnical investigations using state-of-the-art geophysical equipment be conducted to accurately assess the size, volume, and structural characteristics of the reservoir at the selected site. These investigations revealed a substantial deviation from the assumed probability value. The geological features identified indicated a highly promising reservoir structure. As a result, the probability of success was revised to 0.5 (or 50%), and the area was reclassified as highly explored. This 30% increase in the probability of success has significant economic implications, which are discussed in the following sections.

4.0 RESEARCH METHODS

This study focuses on an oil exploration zone located in the Khyber Pakhtunkhwa Province of Pakistan. The study area, illustrated in Figure 2, lies approximately 250 kilometres from Islamabad, the capital city. The region, known for its hydrocarbon potential, witnessed its first oil discovery in 2009. Since then, it has attracted significant exploration activity, with multiple companies operating in the area. Geologically, the belt is dominated by sedimentary rock formations that host substantial oil and gas reserves. Current oil production from the fields exceeds 19,000 barrels per day, while the total estimated recoverable reserves are around 177 million barrels. Approximately 20% of this hydrocarbon-rich belt is under private ownership, and around 16 private firms are

Figure 2: Location of research area

actively involved in exploration efforts. The remaining 80% is managed by the government. However, a major limitation faced by most exploration companies operating in the region is the lack of access to advanced reservoir investigation technologies. As a result, many firms rely on conventional rule-of-thumb approaches rather than detailed geotechnical assessments. This reliance stems from two key challenges: first, the unavailability of state-of-the-art equipment, and second, the financial constraints that hinder companies from acquiring such technologies or hiring specialised expert teams for comprehensive geological investigations.

A comprehensive research methodology was employed for this study, encompassing both qualitative and quantitative approaches. An in-depth site analysis was conducted, complemented by consultations with key stakeholders to gain a nuanced understanding of the area's exploration dynamics. Interviews were held with 20 geotechnical experts and geologists to assess the current geological conditions of the site. Additionally, meetings were conducted with 30 exploration specialists, 10 private investors, and 10 senior executives from companies actively engaged in hydrocarbon exploration within the region. Field visits were made to three operational oil wells, where primary data related to the reservoir was gathered through direct interaction with 50 skilled field workers. Furthermore, critical technical information regarding reservoir characteristics was obtained from officials representing nine oil-extracting firms operating in the belt.

Insights from these interviews and field observations revealed that most private exploration firms relied on a fixed 20% probability of success as a rule of thumb when calculating the expected monetary value (EMV) of exploration projects. This reliance often led companies to bypass comprehensive geotechnical and geological investigations as a cost-saving measure. Notably, discussions with experts indicated that in a few isolated cases, formal investigations had been conducted and appeared to validate the 20% success probability. These rare confirmations reinforced the belief among practitioners that the assumed probability figure was accurate and applicable across the entire exploration belt. A detailed summary of the primary data collection process and sample characteristics is presented in Table 2.

Table 2 provides an overview of the composition and key characteristics of the respondents involved in the primary data collection process for this study. The survey and interviews included a total of 120 participants, categorised into five distinct groups relevant to the oil exploration sector. The first group comprised 20 geotechnical and geological experts, all of whom held graduate-level or higher qualifications. These experts were selected for their technical understanding of subsurface conditions and contributed valuable insights into site-specific geological attributes. Their age range started from 25 years and above, and there was no gender restriction in the selection process. The second group included 30 exploration specialists, representing professionals directly involved in planning and executing exploration activities. While their detailed demographic information was not specified in the table, their inclusion was essential to understand operational strategies and risk perceptions within the industry. The third and fourth groups consisted of 10 private investors and 10 executives from exploration firms, respectively. These respondents provided perspectives on financial decision-making, investment risk tolerance, and strategic management of exploration ventures in the study area. Lastly, 50 skilled workers from three operational oil wells were surveyed. These individuals contributed first-hand operational knowledge and field-based observations, which helped validate technical and economic assumptions used by companies. Overall, the diverse and targeted composition of the sample ensured a well-rounded and representative data set, capturing viewpoints across technical, financial, executive, and operational domains within the hydrocarbon exploration sector.

Table 2: Characteristics and composition of survey sample for primary data collection and interviews

Composition	Size	Education	Age	Gender
Geotechnical/ geological experts	20	Graduate and above	From 25 years onwards	No gender bias
Exploration experts	30			
Investors	10			
Firms' executives	10			
Skilled workers	50			

Based on the initial information, the Expected Monetary Value (EMV) of the project was calculated using a 20% probability of success. However, the results derived from this estimate were not encouraging. To gain a clearer understanding of the reservoir and generate solid evidence to support a go/no-go decision for exploration, comprehensive geotechnical investigations were conducted using advanced geophysical equipment. These investigations had two primary objectives: first, to validate the previously assumed 20% probability of success; and second, to obtain detailed geological data regarding the size, volume, and structural characteristics of the oil reservoir.

The findings from these geotechnical investigations revealed a significantly higher probability of success, along with more favourable geological conditions than previously assumed. Consequently, the economic analysis was updated, and the EMV was recalculated. The revised estimates were far more promising and indicated strong economic viability. These improved results provided decision-makers and project planners with the confidence needed to move forward with exploration activities at the selected site. The overall research design followed for this study, including all major steps, is illustrated in Figure 3.

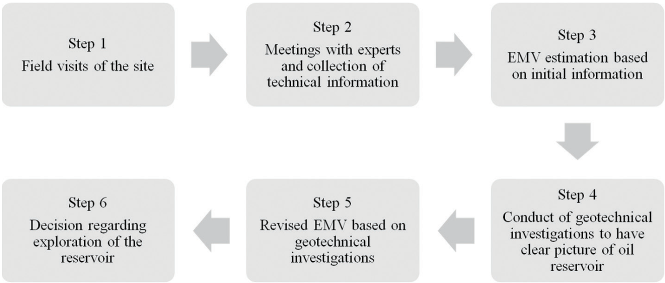

Figure 3: Research design

5.0 ECONOMIC ANALYSIS BEFORE GEOTECHNICAL INVESTIGATIONS

According to available geological data about reservoir, expected oil reserves was estimated as 100 million barrels. An oil reserve is the quantity of oil that can be obtained from reservoir at a feasible cost estimated at present oil prices. Furthermore, based on primary and secondary data collected from different oil exploration firms, economic analysis was carried out to estimate expected monetary value. Using equation 1 and values gathered from available geological data, the expected monetary value was calculated as under.

Expected monetary value
= [Net present value x probability of success-cost of failure x probability of failure]

Mathematically expected monetary value can be expressed by equation (2).

$$\text{Expected monetary value (EMV)} = [(\mathrm{r} \times \lambda_s) - \{\mathrm{r_c}\,(1 - \lambda_s)\}] \quad (2)$$

In equation (2), different values are as under.
Reward, r (NPV) = 94 million US$

Probability of success, $\lambda_s = 20\% = 0.2$ (rule of thumb value for this hydrocarbon belt). Probability of success is the ratio of successful attempts over all outcomes. It is basically parameter of the expectation curve, indicating chances of more than some minimum value.

Risk capital, $\mathrm{r_c} = 20$ million US$. Risk capital refers to funds allocated for speculative activity. These funds are expendable in exchange for large comparative gains. However, investors must be willing to lose all their risk capital in hydrocarbon exploration projects. It is actually the cost of failure.

$$\text{Expected monetary value (EMV)} = [(94 \times 0.2) - \{20(1 - 0.2)\}]$$
EMV = 18.8 – 16
EMV = 2.8 million US$

This value was not very encouraging. It showed marginal economic benefit of drilling at this site. To take a plausible decision about exploration, estimation of breakeven possibility of success was important. Breakeven possibility of success was estimated by replacing ‘λ_s’ with ‘λ_{be}’ in equation (2) and putting EMV = 0 as shown below.

$$\text{Expected monetary value (EMV)} = [(\mathrm{r} \times \lambda_s) - \{\mathrm{r_c}\,(1 - \lambda_s)\}]$$
$$0 = [(\mathrm{r} \times \lambda_{be}) - \{\mathrm{r_c}\,(1 - \lambda_{be})\}]$$
$$\mathrm{r} \times \lambda_{be} = \mathrm{r_c}\,(1 - \lambda_{be})$$
$$\lambda_{be} = \frac{\mathrm{r_c}}{\mathrm{r} + \mathrm{r_c}} \quad (3)$$

Putting values in equation (3), we have

$$\lambda_{be} = \frac{20}{94 + 20}$$
$$\lambda_{be} = 17.54\ \%$$

Breakeven probability of success estimation gave blur picture so exploration effort was required to be analysed for success capacity (SC) to take plausible decision about drilling on the site. Success capacity was calculated by equation (4).

$$\mathrm{SC} = \frac{1}{\lambda_{be}} - 1 \quad (4)$$

Putting values in equation (4), we have

$$\mathrm{SC} = \frac{1}{0.1754} - 1$$
SC = 4.70 say 5

This was very important result. This meant that one success well can carry five dry wells and still has positive net present value. These results were plotted on breakeven graph which is shown in Figure 4.

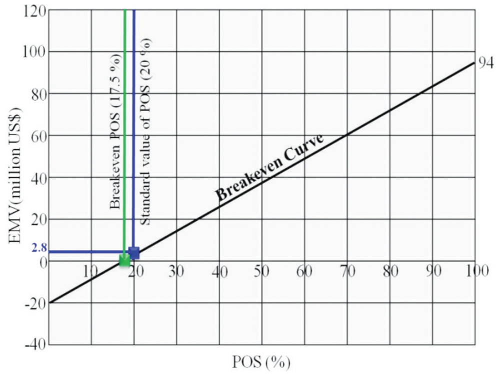

Figure 4: Breakeven before geotechnical investigations

6.0 GEOTECHNICAL INVESTIGATIONS

Since the geological characteristics of reservoir strata cannot be directly observed, indirect methods are employed to estimate the size of the reservoir and the potential recoverability of its resources. These estimations inherently involve a degree of uncertainty, depending on the quality and reliability of the geological data and how it is interpreted. Experts examine the subsurface rock layers to identify optimal locations for drilling, with oil and gas deposits commonly found at depths ranging from 0.5 to 3 kilometres. Naturally, the cost of drilling tends to rise with increasing depth, assuming other factors remain constant.

For an accurate economic evaluation of a reservoir's potential, reliable geological data is essential. This data is typically obtained through site-specific geotechnical investigations utilising modern technology. A variety of advanced tools and techniques are applied, generally falling into three broad categories: geophysical methods, remote sensing, and test well drilling.

Among geophysical techniques, methods such as electrical resistivity, magnetometry, and seismic reflection are widely used to analyse the characteristics of subsurface rock formations. Electrical resistivity readings help infer the type and condition of geological layers by comparing them with known values from different rock types. Seismic methods, particularly reflection techniques, are used to visualise underground structures and determine the composition and shape of the reservoir rock. These methods are generally effective to depths of up to one kilometre, though resistivity equipment can be deployed deeper by lowering it into pre-existing wells.

Remote sensing, on the other hand, involves capturing imagery of the surface terrain via aerial or satellite platforms. These images are then interpreted by experts to identify features indicative of promising drilling zones. In cases where modern equipment is unavailable or unaffordable, drilling a test well, commonly known as a "wildcat well", may be considered. Although this approach is expensive and generally avoided, its significant advantage lies in its ability to reach any desired depth, providing direct evidence about the presence and quality of underground resources. However, as depth increases, so does the cost exponentially.

The research area under study had a well-established history of oil exploration. It was generally believed that a sedimentary rock reservoir containing oil was present at a shallow depth of approximately 0.35 kilometres, although this assumption lacked scientific confirmation. Despite this uncertainty, all exploration firms operating in the region had achieved successful outcomes, largely by relying on a conservative, rule-of-thumb value for the probability of success. These companies showed little interest in conducting detailed scientific investigations to better understand the geological structure of the reservoir. Instead, their approach centred on drilling as quickly as possible to begin extraction, reflecting a more traditional and less scientific method of exploration.

In this study, when the initial economic analysis was conducted using the commonly accepted probability value, prior to any geotechnical investigations, the results appeared vague and suggested only marginal economic viability. While the analysis did not point toward outright failure, it lacked the clarity required for making a confident investment decision. As a result, the decision to proceed with exploration was deferred until after geotechnical investigations could be performed.

To address the uncertainty and obtain accurate information on the reservoir's size, volume, and geological structure, a comprehensive geophysical survey was conducted using state-of-the-art equipment. The Super Sting system, a modern electrical resistivity imaging tool, was employed to produce a three-dimensional subsurface profile of the site, as illustrated in Figure 5. The total cost of this advanced survey was approximately USD 0.5 million. This relatively modest investment significantly reduced uncertainty and provided a much clearer understanding of the reservoir's geological characteristics, enabling more informed decision-making and reinforcing the economic potential of the site.

Recorded data was processed by interfaced computer and results were obtained as digital picture of subsurface strata showing geological features and structures. Digital sketch obtained from geophysical survey is shown in Figure 6.

The results revealed the presence of three large oil reservoirs beneath the site, as illustrated in Figure 6. This discovery significantly reduced the uncertainties surrounding various geological aspects of the reservoir. With the clear and accurate depiction of the subsurface structure, the probability of success was revised upward from the rule-of-thumb value of 20% to 50%. Furthermore, the estimated volume of recoverable oil reserves increased substantially, reaching approximately 300 million barrels, three times higher than previously anticipated. On the financial side, the required risk capital rose from USD 20 million to USD 30 million. However, this increase was offset by the higher projected returns, as the estimated Net Present Value (NPV) improved from USD 94 million to USD 162 million due to the substantial rise in expected oil output.

Figure 5: Equipment used for geophysical survey

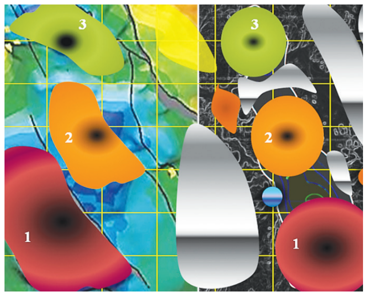

Figure 6: Digital model of geophysical survey

7.0 ECONOMIC ANALYSIS AFTER GEOTECHNICAL INVESTIGATIONS

Geotechnical investigations significantly reduced the level of uncertainty. With clearer insights into the size, volume, and structure of the oil reservoir, the probability of success (POS) improved considerably. It was confirmed that the reservoir was larger than previously anticipated. As a result, the revised POS was established at 0.5, and the updated estimate for potential oil discovery stood at approximately 300 million barrels. Consequently, the economic analysis was recalculated using these new input values, as detailed below.

Reward, r (NPV) = 162 million US$
Probability of success, $\lambda_s = 50\% = 0.5$
Risk capital, r_c = 30 million US$

Using the preceding equations (1), (2) and (3), results obtained were clear and encouraging. Expected monetary value (EMV) came out to be 66 million US$. Breakeven possibility of success (BPOS) came out as 15.6%. Similarly, success capacity (SC) came out to be 5.4. These results were graphed as shown in Figure 7. As indicated by graph in Figure 7, geotechnical investigations reduced the uncertainties and improved the results as compared to results before geotechnical investigations. Company officials were informed about the improved state. They were in a position to take clear decision.

8.0 COMPARISON OF RESULTS

Table 3 presents a comparative assessment of key project indicators before and after conducting geotechnical investigations at the selected oil exploration site. This comparison aims to highlight the impact of scientific investigations on reducing uncertainty and improving the economic viability of the project. The table summarises changes in probability of success (POS), expected monetary value (EMV), net present value (NPV), required risk capital, breakeven POS, and success capacity. These indicators provide critical insights into how data-driven analysis enhances the reliability of investment decisions in high-risk exploration ventures.

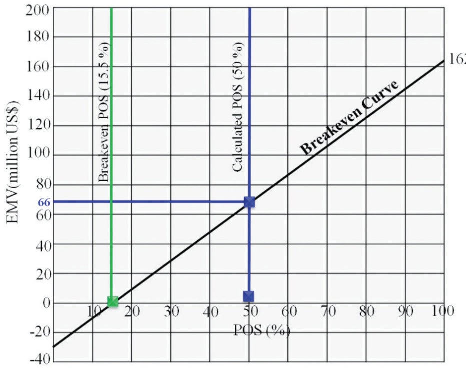

Figure 7: Breakeven after geotechnical investigations

Table 3: Comparison of results

Features	Value Before Geotechnical Investigations	Value After Geotechnical Investigations	Increase or Decrease
Possibility of Success (POS)	20%	50%	+30%
Reward (NPV)	94 million US$	162 million US$	+68 million US$
Risk capital	20 million US$	30 million US$	+10 million US$
EMV	2.8 million US$	66 million US$	63.2 million US$
Breakeven POS	17.5 %	15.6 %	- 1.9
Success capacity	5	6	+1

The interpretation of Table 3 and related effects are summarised below.

- Probability of Success (POS): Increased from 20% to 50%, reflecting a 30% gain. This indicates that geotechnical investigations significantly enhanced confidence in the success of the project by providing better insights into the reservoir's characteristics.
- Net Present Value (NPV): Rose from 94 million USD to 162 million USD, showing an increase of 68 million USD. This improvement highlights a substantial rise in the project's financial attractiveness.
- Risk Capital: Increased moderately from 20 million USD to 30 million USD. While this suggests a slightly higher upfront investment, the corresponding increase in expected returns justifies the additional risk.
- Expected Monetary Value (EMV): Showed a dramatic increase from 2.8 million USD to 66 million USD, a difference of 63.2 million USD. This 225% improvement reflects the transformative impact of accurate geological data on financial decision-making.
- Breakeven POS: Declined from 17.5% to 15.6%, suggesting that the project now requires a lower threshold of success probability to remain viable. This makes the project more robust even under less favourable conditions.
- Success Capacity: Increased from 5 to 6, indicating enhanced technical or operational readiness to achieve successful outcomes.

The comparison clearly illustrates the value of geotechnical investigations in de-risking the project and improving financial viability. With a substantial increase in EMV and NPV, and a reduced breakeven POS, the post-investigation scenario presents a far more favourable outlook. These improved metrics provide a strong basis for moving forward with the exploration phase, ensuring that decisions are supported by solid technical and economic evidence.

9.0 CONCLUSIONS AND POLICY RECOMMENDATIONS

The findings of this study clearly demonstrate that geotechnical investigations significantly reduce uncertainties and provide a much clearer understanding of the economic potential of oil exploration projects. One of the central objectives of this research was to assess how technical investigations, particularly using modern geophysical tools, can improve the accuracy of economic decision-making in high-risk ventures. The results confirmed that prior technical investigations offer tangible benefits, not only in terms of improved estimates of resource quantity and structure, but also in enhancing the reliability of expected monetary value (EMV), net present value (NPV), and probability of success (POS).

Beyond this specific case, the study highlights a broader lesson: economic analysis should ideally be preceded by technical investigations in all types of industrial and development projects. For example, in a social initiative such as constructing a hospital, pre-construction geotechnical studies are essential to determine whether the subsurface conditions can safely support the intended structure. Similarly, infrastructure development like roads, railways, or marine works also demands thorough geotechnical analysis to accurately predict construction costs and ensure structural longevity.

Emerging applications of geotechnical techniques in fields such as earthquake risk analysis, geo-hazard mapping, waste management, and soil science further emphasise their growing relevance. The study cautions against reliance on pre-assumed values or rules of thumb, particularly in high-stakes initiatives such as hydrocarbon exploration, where uncertainty is inherent and consequences of error are significant.

As evidenced in this case study, integrating modern technical tools and investigative methods can turn vague, uncertain scenarios into well-informed, economically viable decisions. This approach not only improves project clarity but also bolsters confidence among planners, investors, and stakeholders. The research thus opens a promising avenue for future studies, encouraging the use of advanced geotechnical investigations as a means to reduce risk and uncertainty across diverse sectors.

10.0 POLICY RECOMMENDATIONS

Based on the insights drawn from this case study, the following policy recommendations are proposed to improve the quality of decision-making in oil exploration and other infrastructure initiatives:

- **Mandatory Geotechnical Investigations Prior to Investment Approval:** Regulatory authorities should require that all exploration and major infrastructure projects undergo comprehensive geotechnical investigations before project approval or financing. This will reduce uncertainty and ensure sound economic evaluations based on factual geological data.
- **Discouragement of Rule-of-Thumb Practices:** Policymakers and industry regulators should discourage the use of generalised or outdated probability values (e.g., a 20% rule-of-thumb for success) in feasibility assessments. Site-specific data must be prioritised over heuristic shortcuts.
- **Integration of Technical and Economic Analysis:** Project evaluation frameworks should be revised to mandate that technical investigations (such as geophysical surveys) are conducted and analysed before conducting economic analysis. This sequencing improves the precision of investment decisions.
- **Standardisation of Geotechnical Investigation Protocols:** Standards or sector-specific guidelines should be developed for conducting and validating geotechnical investigations. These protocols should define the minimum technical requirements for exploration and infrastructure development projects.
- **Capacity Building in Modern Geotechnical Methods:** Government bodies, research institutions, and industry associations should invest in training programs to build expertise in modern geophysical and geotechnical investigation tools and interpretation methods. This will enhance the reliability of data used in project evaluations.
- **Incentivising Use of Modern Equipment:** Governments may consider providing financial incentives (e.g., tax rebates, subsidies, or access to public financing) for exploration firms that utilise state-of-the-art geotechnical technologies, thus promoting better risk assessment practices.
- **Strengthening Public-Private Collaboration:** Public agencies and private sector exploration firms should be encouraged to collaborate in sharing geotechnical data and survey results, especially in regions with complex geology. This can reduce duplication of effort and improve national resource mapping.
- **Application beyond Oil Exploration:** These recommendations are equally relevant for infrastructure sectors such as transport, water, energy, and urban development. Policymakers should adopt a cross-sectoral approach to institutionalise technical investigations as a prerequisite for large-scale investments.

CONFLICT OF INTEREST DECLARATION

Author declares that there are no conflicts of interest.

INFORMED CONSENT DECLARATION

All participants were provided with detailed information about the purpose, procedures, potential risks, and benefits of the study. Informed consent was obtained prior to participation, and participants were informed of their right to withdraw from the study at any time without penalty. ■

REFERENCES

[1] Ali, L., & Gul, E. (2011). Use of new geophysical equipment in geotechnical site characterization. In *Contemporary topics on testing, modeling, and case studies of geomaterials, pavements, and tunnels.* https://doi.org/10.1061/47626(405)19

[2] Ali, S., Khan, M. A., & Ahmad, A. (2021). Economic assessment of prospective shale gas play in Pakistan using discounted cash flow model. *Arabian Journal of Geosciences, 14*(14), Article 1211. https://doi.org/10.1007/s12517-021-08766-w

[3] Anees, M., Abid, A., Baig, M. N., & Khan, A. (2022). Hydrocarbon potential assessment of the Meyal Oil Field using machine learning and petrophysical techniques. *ACS Omega, 7*(48), 43617–43630. https://doi.org/10.1021/acsomega.2c05759

[4] Ashraf, A., Malik, A., & Rafiq, M. (2019). Reservoir facies classification using well log and 3D seismic data: A case from the Sawan gas field, Pakistan. *Arabian Journal of Geosciences, 12*, Article 726. https://doi.org/10.1007/s12517-019-4843-2

[5] Bickley, H., & Michel, G. (2018). Insurance pricing and portfolio management using catastrophe models. In *Risk modeling for hazards and disasters* (pp. 235–246). Elsevier. https://doi.org/10.1016/B978-0-12-804071-3.00010-0

[6] Brealey, R. A., Myers, S. C., Allen, F., & Mohanty, P. (2018). *Principles of corporate finance* (12th ed.). McGraw-Hill Education.

[7] Bui, L. H., Nguyen, V. C., & Tran, T. A. (2024). Integration of machine learning and numerical simulation in reservoir characterization. *Petroleum Research, 9*(2), 123–136. https://doi.org/10.1016/j.ptlrs.2024.01.003

[8] Chittumuri, P., Gummadi, S., & Sudhakar, D. (2025). *GIS and ML-based risk analysis of pipeline failure in the oil and gas sector* (arXiv:2501.11213). arXiv. https://arxiv.org/abs/2501.11213

[9] Discover Geoscience. (2024). Optimizing reservoir characterization through integrated seismic and petrophysical data analysis. *Discover Energy, 8*(2), 99–114.

[10] Domingues, N. (2019). Prospection techniques for oil and shale gas. *International Journal of Petrochemistry and Research, 3*(1), 243–248. https://doi.org/10.18689/ijpr-1000142

[11] Fathi, A., Ghasemi, H., & Fattahipour, H. (2023). Full-waveform inversion for 3D velocity profiling in complex media. *Geophysical Journal International, 233*(1), 115–134. https://doi.org/10.1093/gji/ggac543

[12] Gopalakrishnan, P. (2022). Impact of modern exploration techniques in oil & gas reserves to production ratio. In *Innovative exploration methods for minerals, oil, gas, and groundwater for sustainable development* (pp. 405–421).

Elsevier. https://doi.org/10.1016/B978-0-12-823998-8.00031-4

[13] Hanaei, H., Ghazavi, M., & Torabi, A. (2020). Effects of hydrocarbon contamination on geotechnical properties of sandy soils. *Environmental Geotechnics, 7*(4), 234–244. https://doi.org/10.1680/jenge.18.00081

[14] Hussain, Z., Khan, M. A., & Zafar, A. (2024). Rock physics modeling of clastic reservoirs: A case study from the Lower Goru Formation, Middle Indus Basin, Pakistan. *Journal of Petroleum Exploration and Production Technology, 14*, Article 134. https://doi.org/10.1007/s44288-024-00076-4

[15] Ibarra, M. V., Oluyemi, G., & Petrovski, A. (2017). Value of information and risk preference in oil and gas exploration and production projects. In *SPE Annual Caspian Technical Conference and Exhibition*. Society of Petroleum Engineers. https://doi.org/10.2118/189044-MS

[16] Lerche, I. (2019). A review of economic risking methods commonly used in hydrocarbon exploration. *Journal of Petroleum Exploration and Production Technology, 9*, 231–244. https://doi.org/10.1007/s13202-018-0602-9

[17] Li, X., Zhao, Y., & Wang, Q. (2025). Geomechanics and reservoir evaluation of fractured reservoirs: Advances in seismic and AI-based interpretation. *Energies, 18*(10), Article 2623. https://doi.org/10.3390/en18102623

[18] Lutenegger, A. J. (2019). Geotechnical site investigations. In *Soils and geotechnology in construction* (pp. 53–110). CRC Press. https://doi.org/10.1201/9781315380643-2

[19] Makhotin, A., Zhdanov, M., & Slobodyan, S. (2020). *De-risking hydrocarbon asset evaluation using machine learning for recovery factor estimation* (arXiv:2010.03408). arXiv. https://arxiv.org/abs/2010.03408

[20] Qadri, R. B., Baig, M. N., & Khan, N. (2022). Gas sands characterization of the Sembar Formation in the Lower Indus Basin, Pakistan. *Frontiers in Earth Science, 10,* Article 1039605. https://doi.org/10.3389/feart.2022.1039605

[21] Ren, X., Zhang, H., & Wei, C. (2022). An integrated economic model for evaluating offshore oil development projects under uncertainty. *Journal of Marine Science and Engineering, 10*(8), Article 1155. https://doi.org/10.3390/jmse10081155

[22] Roustazadeh, P., Hassani, H., & Samani, M. (2022). *Machine learning-based estimation of oil and gas recovery factors* (arXiv:2210.12491). arXiv. https://arxiv.org/abs/2210.12491

[23] Schenk, C. J., & Pollastro, R. M. (2024). *Analog-based methods for estimating undiscovered, technically recoverable oil and gas resources* (USGS Scientific Investigations Report 2024–5011). U.S. Geological Survey. https://doi.org/10.3133/sir20245011

[24] Syed Haider Ali. (2024). Assessing reservoir potential in Pakistan: Strategic and geological insights. *LIRA Journal, 2*(1), 44–58. https://journal.lira.pk/LIRA/article/view/6

[25] Tahir, A., Khan, M. A., Yaseen, M., & Ali, S. (2024). Shale gas potential evaluation using basin modeling in the Kohat Plateau, Pakistan. *Arabian Journal of Geosciences, 17*(4), Article 851. https://doi.org/10.1007/s12517-024-10851-0

[26] Usman, M., & Shah, S. A. A. (2023). Hydrocarbon exploration trends and policy implications in Pakistan. *Pakistan Energy Review, 11*(1), 33–49.

[27] White, J. A., Grasman, K. S., Case, K. E., Needy, K. L., & Pratt, D. B. (2020). *Fundamentals of engineering economic analysis*. John Wiley & Sons.

[28] Xie, Z., Liu, Y., & Li, H. (2023). Evaluating the degree of tectonic fracture development and its control on reservoir productivity. *Energies, 16*(2), Article 2623. https://doi.org/10.3390/en160202623

PROFILE

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