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Civil Engineering

**MANAGEMENT OF INFRASTRUCTURE
PROJECTS GEOTECHNICAL RISKS USING
ANALYTICAL HIERARCHY PROCESS**

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Master's Thesis

Supervisor
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Signature

DEDICATION

To my beloved mother and father, my brother and sisters, and all my friends, you have always respected what I wanted to do and have given me full support and encouragement throughout my life. I would like to express my great appreciation for your great love.



ABSTRACT

MANAGEMENT OF INFRASTRUCTURE PROJECTS GEOTECHNICAL RISKS USING ANALYTICAL HIERARCHY PROCESS

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The risks of infrastructure projects are considered one of the most important areas in engineering project management due to their strategic importance. From this strategy a new approach has been prepared to assess the project risks arising from the geotechnical in southern Iraq. The risks were counted and evaluated through previous studies, questionnaires, and interviews with experts to specify the potential risks of infrastructure projects. The elements of effective risks and the degree of their impact were determined based on 14 types of risks affecting infrastructure projects. The AHP model was created for the purpose of drawing conclusions and compared with RII evaluation method. The study area (the southern region in Iraq) is divided into three main sections according to the type of geological soil, history, and the degree of urbanization in each area to determine the variation in the types of geotechnical risks. The flexibility of the system was tested using other factors such as project size and project excavation depth. The results were significant, and the risk prognosis was excellent, according to expert opinion.

Keywords: Geotechnical Risk Assessment, AHP, RII, Infrastructure Projects.

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ABBREVIATIONS

AI	:	Artificial Intelligence
FSK	:	Frequency Shift Keying
IoT	:	Internet of Things
PAN	:	Personal Area Network
OFDM	:	Orthogonal Frequency Division Multiplexing
TDMA	:	Time Division Multiple Access

1. INTRODUCTION

Risk management was growing due to the changes in characteristics of the systems and facilities that was planned. Technological, geological, contractual, and organizational circumstances all contribute to geotechnical project risks. Geotechnical risks are frequently linked to one another, resulting in an increase in the project's cost and schedule [1]. The project's overall quality has also slipped below expectations. Inadequate information or limited knowledge of geotechnical behavior and conditions can have a negative impact on a project's occupational, technical, and financial performance. They may result in disagreements during project implementation, the reconstruction of some works, environmental damage, completion delays, and quality issues [2]. It may also have an impact on the workers' safety and health. These occurrences can have a detrimental impact on a construction project, such as income loss, time delays, or increased operational or maintenance costs [3]. Because geotechnical hazards exist, numerous scholars have developed a project management statistic for geotechnical engineering projects that focuses on risks. The state of art researches in hazards in geotechnical infrastructure projects highlighted disparities between final costs and tender costs were observed in contracts, with the tender cost being surpassed on average by 32% [4]. Kerim Koc et al. in [3] conducted a study in Turkey in 2020 with the participation of 47 civil construction specialists. They estimated the rank of each risk in terms of cost and schedule using correlation analysis based on index theory. The most significant risk factors were determined to be "organic silts, soft clays, or peat." The findings of this study can be applied to infrastructure projects to pinpoint the causes of schedule and expense overruns due to geotechnical issues. Cost and time overruns, according to Viitanen et al, 2017, are partly caused by changes in project scope and are linked to an inability to manage geotechnical hazards appropriately during planning, design, and construction [5]. In 2017, Szymański et al. identified and classified significant types of risks in projects: legal, physical, financial, political, construction, environmental, design, and contractual risks, based on the nature of the impact[6].

1.1 GEOTECHNICAL RISK MANAGEMENT

Due to the difficulty in identifying geotechnical conditions, infrastructure projects were termed unknown environments. As a result, the identification of geotechnical concerns is sometimes hampered by a lack of understanding of the site's geotechnical conditions. The majority of the researchers looked into geotechnical issues on their own. In 2018, Abu Safayet et al, investigated the polarity of failure calculations, internal erosion, and soil and rock attributes [4]. In 2017, Shipton et al, in 2012 investigate hazardous geotechnical situations, as well as contributing variables, mitigating options, and probable repercussions [7]. In 2019, Barr et al discussed the soil risks for mitigating geotechnical concerns. Furthermore, the geotechnical design codes for the entire structure meet the requirements for bearing capacity, durability, geometrical characteristics, and stability, as well as environmental effect and working conditions. The construction process, the contract, the organization, and the economic arrangements are all key hazards in geotechnical engineering projects. Hazard, risk item, warning bells, beginning event, harm event, and damage are all important elements in this process [8].

Controlling geotechnical risk requires an in-depth knowledge of project aspects. Many geotechnical engineering projects and conditions are characterized by a wide range of challenging circumstances, including lengthy project timelines, significant uncertainties, a wide range of diverse needs, large and multifaceted organizations, a high level of technical expertise, and a focus on politics, the public, and the environment. Many various actors are involved in the construction process, many of whom have competing interests and no experience working together. Many geotechnical engineering work activities, such as foundation work, excavations, and tunnelling, can be classified as series systems. The order in which work activities are completed is determined by prior work processes and has an impact on subsequent work activities [9]. ISO 31000 is concerned with the "risk source" and "consequence" in this regard. They describe a risk source as a "factor that, alone or in combination, has the intrinsic ability to cause risk." The "appearance or modification of a given set of circumstances" is defined as an event, while the "result of an event influencing objectives" is defined as a consequence [2].

1.2 RISK ANALYSIS AND EVALUATION

The process of understanding each of the identified risks is known as risk analysis. It requires input to assess the risks that must be addressed and to determine the most cost-effective risk management techniques. It comprises the risk sources as well as the implications of those risks. The outcomes and likelihoods are frequently combined to evaluate and analyze risks. Risk assessments can be qualitative, quantitative, or semi-quantitative. The common risk evaluation tools and analyses used in geotechnical engineering can be summarized as follows [10][1]:

- a) Fault tree analysis (FTA)
- b) Event tree analysis (ETA)
- c) Consequence or cause-consequence analysis

Also, the used techniques for analyzing safety incidents, complex risks and critical controls can be adapted by the types being presented in below [11][12]:

- a) Probabilistic risk analysis (PRA)
- b) Decision analysis
- c) Multi-risk analysis
- d) Analytical hierarchy process (AHP)
- e) Bayesian networks

1.3 PROBLEM STATEMENT

Due to the variability and heterogeneity of geotechnical properties and the limited scope of site investigations, designers in complex infrastructure projects face ambiguous geotechnical conditions. Natural soil deposits are frequently characterized by irregular layers caused by a variety of materials with different effective properties that affect the material's behavior[13]. Similarly, irregular systems can be found in rock materials, which might impact the rock's behavior. Furthermore, selecting appropriate soil parameters for use in design conditions and modeling geotechnical behavior is difficult. As a result of the high sensitivity to changes in

implementing infrastructure projects caused by a disruption or delay in work activities, Many times, geotechnical risks have a significant impact on the project's costs and schedule. This typically leads in time delays and higher expenditures, which are often permanent. Events that have a negative influence on a business's reputation, income, or extra expenses for development, operation, or maintenance may be avoided if the associated risks are adequately handled. The adequate safety margin must be used to ensure the infrastructure project's safety[14]. It is necessary to consider geotechnical concerns in order to establish the best possible safety margin for infrastructure projects. The design and execution of site investigations are influenced by geotechnical concerns in infrastructure project considerations. The key difficulty in this research is to figure out how to examine the best strategy for managing infrastructure projects based on geotechnical conditions and appropriately identify project hazards.

1.4 OBJECTIVE OF STUDY

The objective of this research is to investigate the geotechnical risks in infrastructure projects and improve management of geotechnical risks by using an independent state of the art method to improve the quality of geotechnical works and to decrease costs and time overruns.

1.5 THESIS ORGANIZATION

There are five chapters in this thesis. In the first chapter, you'll learn about geotechnical risks in infrastructure projects. In addition to the problem statements and objectives, it discusses the background of this field and the main concept of geotechnical risks in infrastructure projects.

The second chapter gives a broad overview of the effects of geotechnical risks in infrastructure projects, based on studies gathered from various studies.

In Chapter three, the solution technique program is presented, which includes the studied parameters, work methodology, and risk element effectiveness testing.

The work's result and calculation are discussed in Chapter 4. The fifth chapter is the final chapter.

2. LITERATURE REVIEW

2.1 GENERAL

Unwanted events related to certain ground conditions generate geotechnical risks to construction projects. Geotechnical risks, like other risks, must be identified and addressed in a systematic risk management approach to avoid schedule and budget overruns, property damage, and human life loss. Geomorphological and geological investigations conducted early in the project's development substantially aid in the reduction of geotechnical risk. However, daily practice is complicated by a frantic project start and a shortage of subsurface data, geological, and geotechnical competence[15]. Infrastructure is built on or in the subsurface, and material from the subsurface is frequently used as a building material. As a result, the subsurface and materials derived from it play an important role in both the planning and construction phases as well as the maintenance phase of any infrastructure. However, the subsoil and materials derived from it are frequently ignored as crucial components of the structure, with sometimes severe repercussions affecting the infrastructure's availability, price, and long-term viability[16]. These issues are frequently caused by a lack of understanding of a simple approach to the heterogeneity of the subsurface during the design and/or construction phases [17]. A portion of the landslide occurred beneath the bridges, causing damage. One of the bridges had to be demolished by blasting, while the other needed to be strengthened[18]. The cost of demolishing and reconstructing the bridges is estimated to be over 11 million euros. As indicated in figure 2.1, the landslide was triggered by filling of soil masses, i.e. loading of the subsurface near the bridges[19].



Figure 2.1: Bridge Damaged by Landslide, Norway [19]

2.2 GEOTECHNICAL RISKS IN INFRASTRUCTURE PROJECTS

2.2.1 Geotechnical Risks in Infrastructure Transportation Projects

Kevin McLain et al. [20] 42 of 50 US state transportation departments took part in the survey. It also looked at 26 DB requests for proposals from 26 states to see the client's thoughts the clients thoughts. Then, it interviewed the other side: 11 structured interviews with DB contractors to see what they thought about the contract. They discovered that the most effective strategy to control pre-award risk is to do a comprehensive geotechnical investigation before to awarding the task. However, the federal government's desire to expedite project delivery, along with financial incentives to employ DB, makes it more likely that state DOTs will use DB to complete large-scale projects that face challenging geological obstacles.

Finally, the question is whether the client is willing to pay through design-contingency for unrealized geotechnical hazards. As a result, the major finding is a strong recommendation that an agency exercise extreme caution when selecting DB project delivery for a project with considerable geotechnical risk.

Nicholas P Koor in [21] does geotechnical research to reduce geotechnical risks by assuring the presence of the appropriate people on-site and effective communication between site employees, the design group, and the contractor. During the project, the conceptual ground model's constant modification was a critical risk management tool. The Foothills Bypass in Hong Kong's New Territories is a dual 2-lane motorway that runs along the western fringe of Tuen Mun. The road crosses a bridge at its northern terminus to reach a grade-separated junction along a 1.7-kilometer embankment in the Tsing Shan foothills. An essential and basic aspect of the activities was stabilizing the already unstable wide area. The stabilizing phase included staged excavation, deep trench drain construction, and filling activities. Pressures, low-strength shear zones, and collapse characteristics all challenged the project's long-term viability and development. Figure 2.2 shows the variety of the Tsing Shan range's geology and geomorphology.

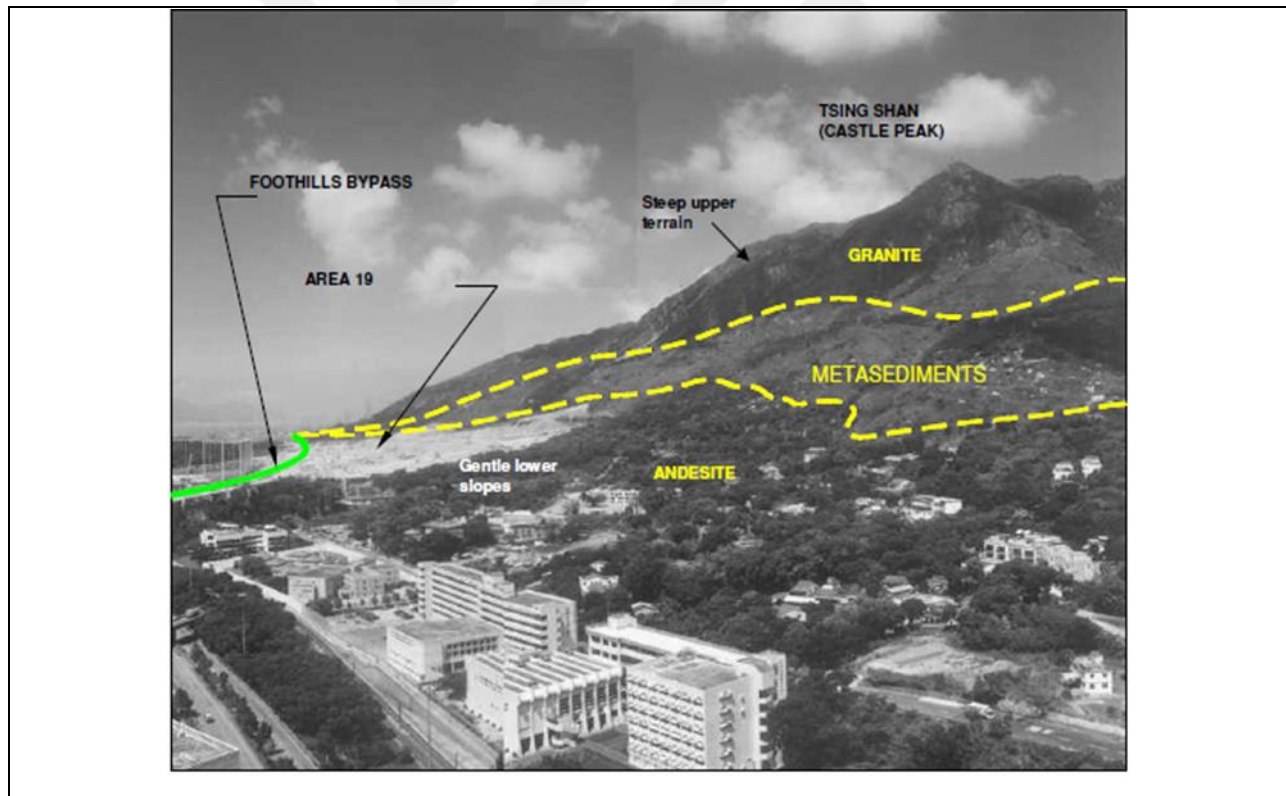


Figure 2.2: Geomorphology and General Geology of the Foothills of TSING Shan[21].

The sequencing of the drainage and earthworks, as illustrated in figure 2.3, was critical to the effectiveness of the slope stabilization and the avoidance of large-scale slope movements in Area 19.

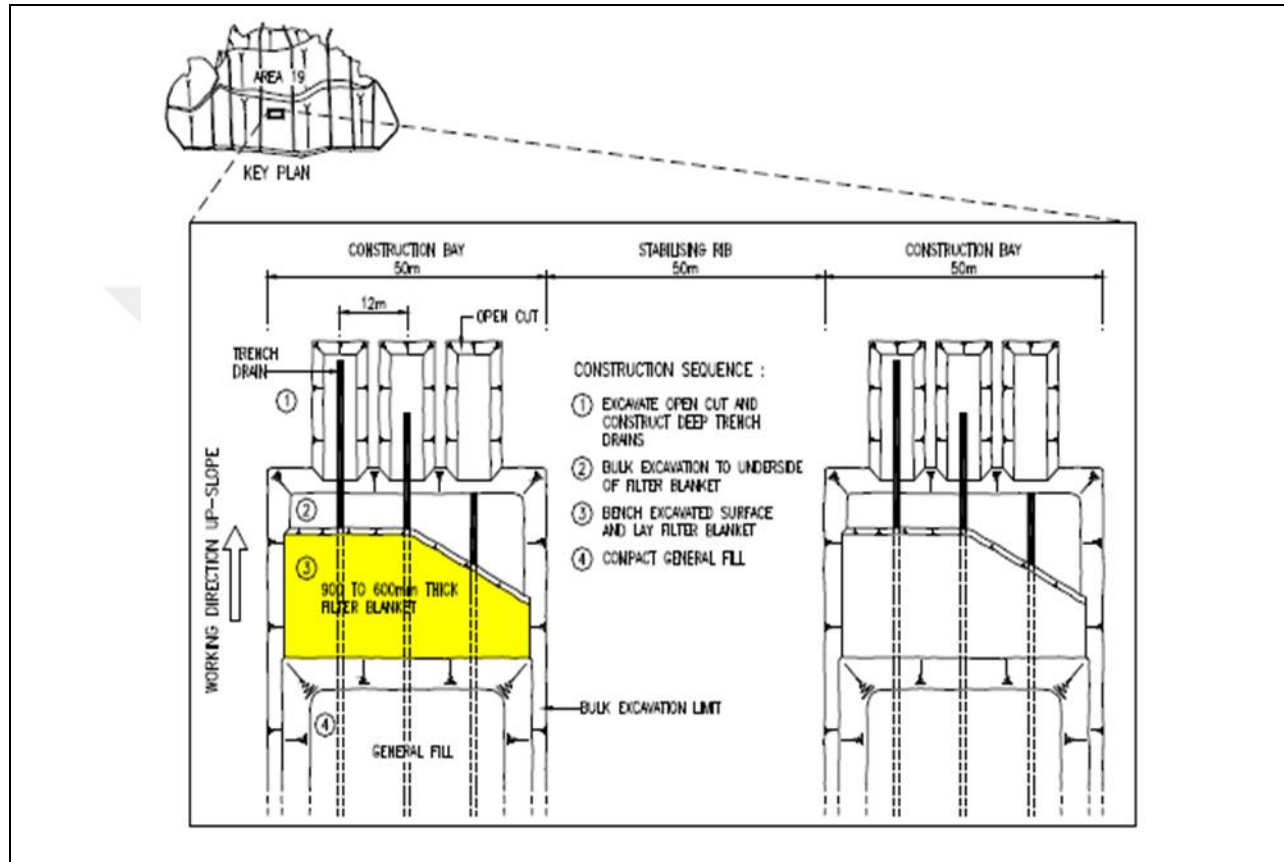


Figure 2.3: Sequence Area in Construction[21].

Reduced geotechnical risk during design and construction was one of the study's primary goals. After construction was completed, Ground model input included data from slope deformation and ground water monitoring in Area 19, as well as other sources. Engineers review and update the ground model on a quarterly basis, according to the specifications. Geotechnical Control for Slopes and Retaining Walls provides an overview of the subject. the mechanical means by which man-made slopes and retaining walls are to be regulated. Any man-made slopes and retaining walls that need long-term geotechnical support must be approved by GEO before construction may begin.

This way makes sure that geological and geotechnical advice and evaluations come from experts who have a lot of experience with projects like this one. When it comes to risk management, even though it's true that the consultants are in charge of everything that's done in the design process, the GEO has become an important part of that process. Because of the complicated ground conditions in Hong Kong and the growing use of super fast-track projects, the author thinks this process is a good way to ensure that major geological hazards aren't missed and that design strategy is used to mitigate these risks. [22].

Amadi Alolote in [23] explores the nature of geotechnical risk variables that can cause cost overruns in transportation infrastructure projects. With this paper, you'll learn about the many methods for mitigating ground hazards throughout the preconstruction phase of highway projects, and how a lack of these methods might lead to a pattern of high-cost overruns.' An investigation into geotechnical practice uncovered a number of heated debates that may have a major financial influence on highway project completion costs. Deterministic pricing approaches that better represent diverse ground conditions, a lack of preparatory geotechnical research, and a lack of geotechnical risk containment in contracts are among the results of this study. According to the study, the gaps in practice revealed could be used as a reasonable theoretical perspective for measuring financial risk in highway projects related to ground conditions. This indicates that poor geotechnical risk management, which is still prevalent in highway companies to varied degrees, can have a significant financial impact on project completion costs. As a result, the dynamics of geotechnical risk aversion might significantly impact the project's final cost accuracy. The theoretical perspective needed to understand the various pathways through which geotechnical risk can cause inefficiency and waste of financial resources on transportation infrastructure projects has been provided to road project clients (highway agencies), who are the primary target audience.

Mike Black [24] outlines the scheme's overall geological background, as well as the major geotechnical risks that were initially recognized. An in-depth analysis of the risks presented by these dangers was aided by a combination of desk research, on-the-ground inquiry, and comprehensive client-led interpretive reporting. Appropriate mitigation was designed to eliminate or decrease these risks to an acceptable level throughout the design and delivery process. A new high-frequency, high-speed suburban rail service servicing London and its

neighboring areas is part of the £148 billion Crossrail project. Crossrail's core region is shown in the geological long-section form in Figure 2.4.

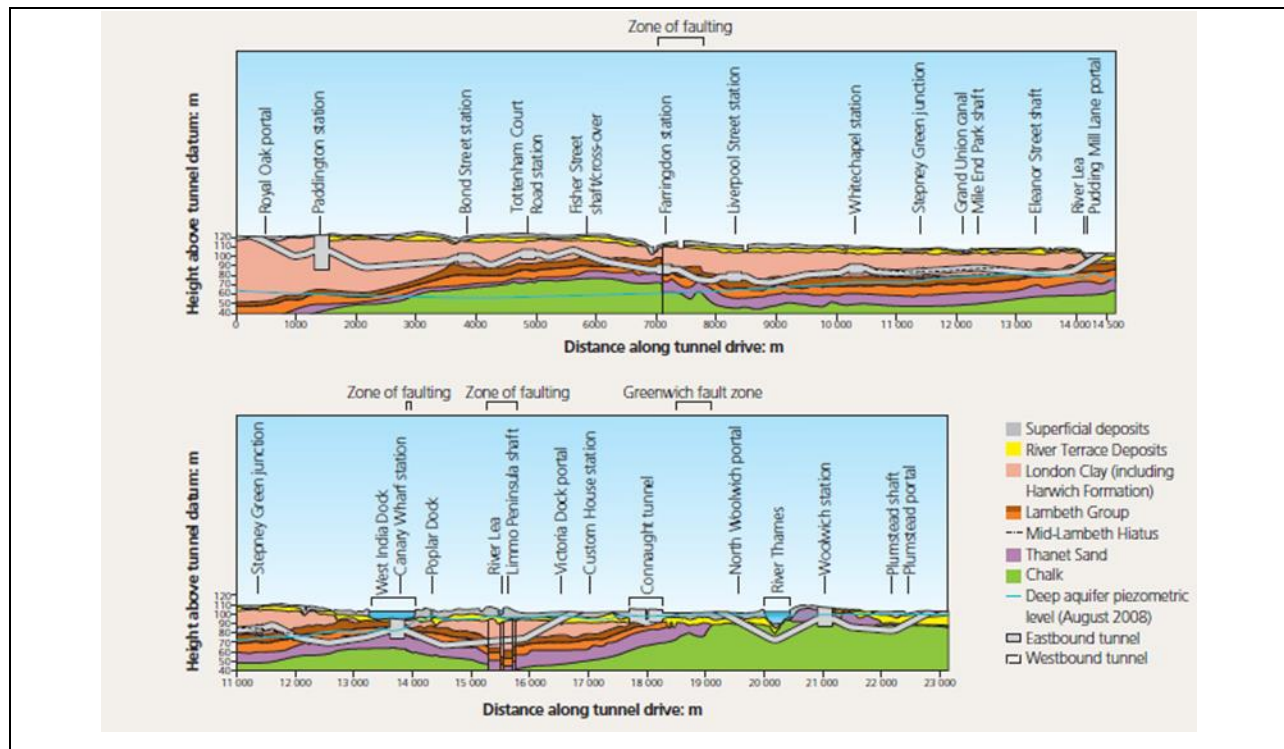


Figure 2.4: Geological Long-Sections of the Central Tunneler Section, Which Forks at Stepney Green[24].

Many of the geotechnical problems that arose during construction had only a modest impact on the program, which is a credit to the thorough and systematic way in which risks were identified, investigated, and mitigated throughout the design phase. Detailed research on the ground and in the office and client-led interpretation reports and lessons learned from previous London building projects enabled risks to be identified, correctly defined, and adequately managed. It's also important to bring up massive initiatives like Crossrail. An excellent chance to interact with academic and industry specialists to increase knowledge and understanding and so continue to decrease risk on the ground in future projects is provided by [25].

By offering unique methodologies and accompanying practical applications, Hongwei HUANG et al. [26] Attempt to share some tunneling-related quantitative risk management experiences from China. The conditional Markov chain, quantitative vulnerability analysis, and field data-based statistics are utilized for environmental impact risk analysis in soil uncertainty analysis.

They have all been shown to work in real-world situations, which is why they were included in the research in the first place. Risk management's dynamic character is highly regarded in the light of the multiple phases and possibilities that a tunnel project possesses. A real-time monitoring system employing LEDs and MEMS, developed in conjunction with WSN, was able to show the danger to workers on the project site in real time. The high-impact low-chance risk is considered in the tunnel lining structure's resilience analysis model. Figure 2.5 displays the results of soil profile simulations performed using the CMP model. One can see in Figure 2.6 how strenuous activities might affect tunnel performance.

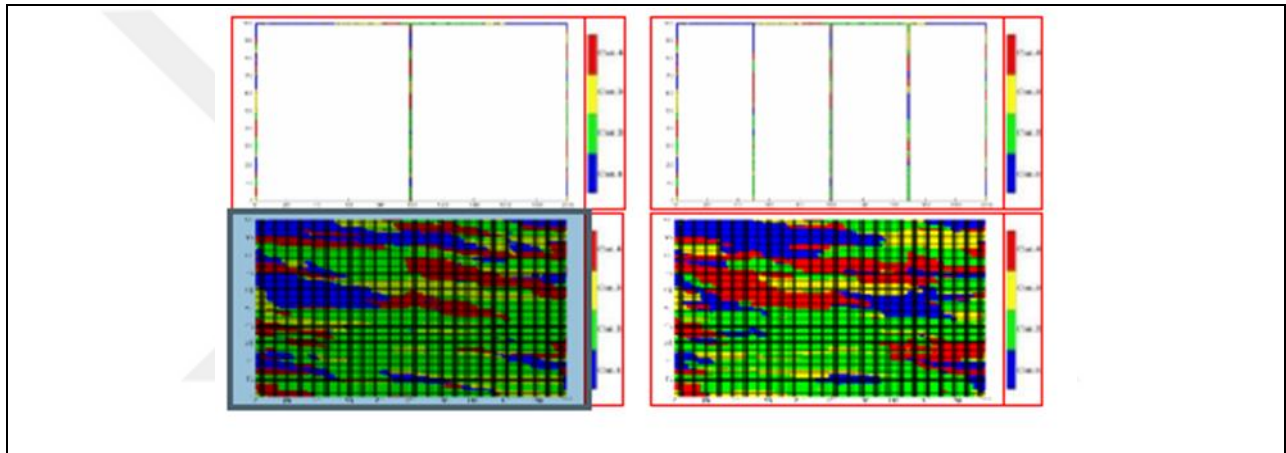


Figure 2.5: Simulations of the Soil Profile by Using the CMP Model [26].

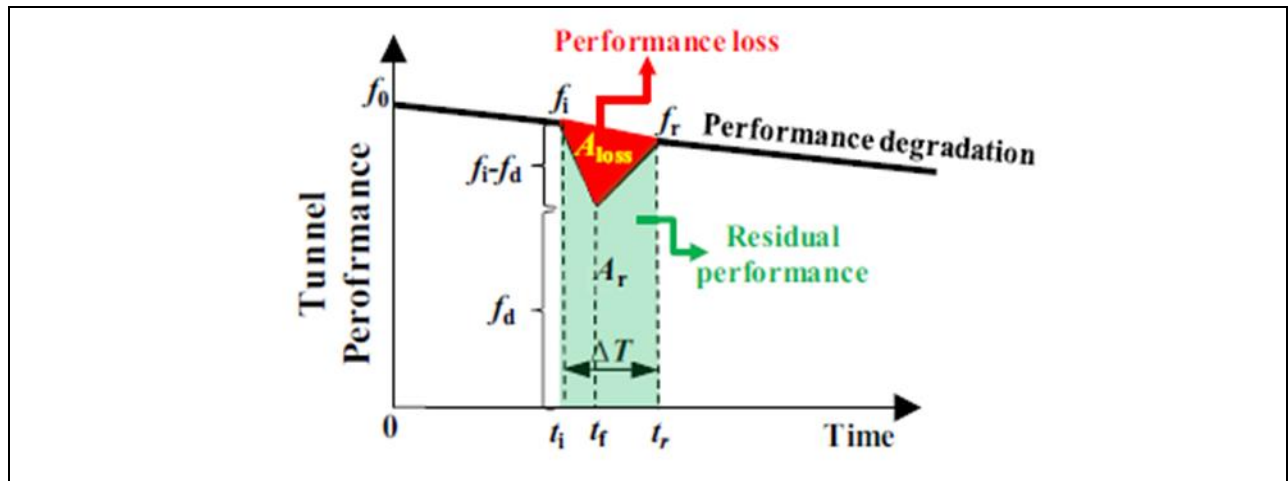


Figure 2.6: Disruption of Tunnel Performance Subjected to Extreme Activities[26].

When conducting China's risk assessment, researchers found that the use of fuzzy fault trees for hazard identification and conditional Markov chains for the likelihood of soil geographical distribution were all used. A case study of structural collapses in China was used to construct the risk acceptability criterion. All of the methods outlined above have been demonstrated to be effective in real-world circumstances.

There must be a thorough understanding of the changing risk throughout the life of tunnel construction in order to manage it properly. Control tunnel safety, especially when hazards are identified qualitatively. It is especially effective to employ newly developed LEDs and MEMs with WSN methods to highlight the danger in real-time to inform workers. The suggested resilience model may estimate the tunnel's resistance to interruption caused by the high-impact low-chance hazard. It is possible to increase the resilience of performance in the face of risk and the speed with which it recovers with little time and expense by using smart monitoring and inspection techniques. Disaster risk may be efficiently handled due to this [26].

2.2.2 Geotechnical Risks in Infrastructure Sewage, Water and Gas Pipelines Projects

Vassilis Marinos et al. investigate the evaluation of landslide hazard and risk along or across the Trans Adriatic Pipeline (TAP) natural gas pipeline project in Albania, which is now underway. [27] This pipeline, stretching across northern Greece and southern Albania, would bring natural gas from the Caspian Sea to Europe and be completed in 2018. Land sliding has long been recognized as a significant issue in the selection of pipeline routes in hilly places, notably in the difficult terrain of central Albania, and it continues to be so today. Because geohazard decision-making is heavily influenced by risk, experience from previous big pipeline projects has shown that hazard avoidance is often the best cost- and time-effective method of reducing landslide risk. The majority of pipeline rupture data in steep terrain comes from landslides, according to industry experience. Landslides should be considered a significant operational risk while operating in steep terrain. The outcome has long been recognized as a significant problem in the choosing of pipeline routes in mountainous places, particularly on unstable right-of-way (RoW) cut slopes such as those encountered with the Trans Adriatic Pipeline (TAP) in Albania (see figure 2.7). Figure 2.8 also depicts a model of the TAP route across the study area.

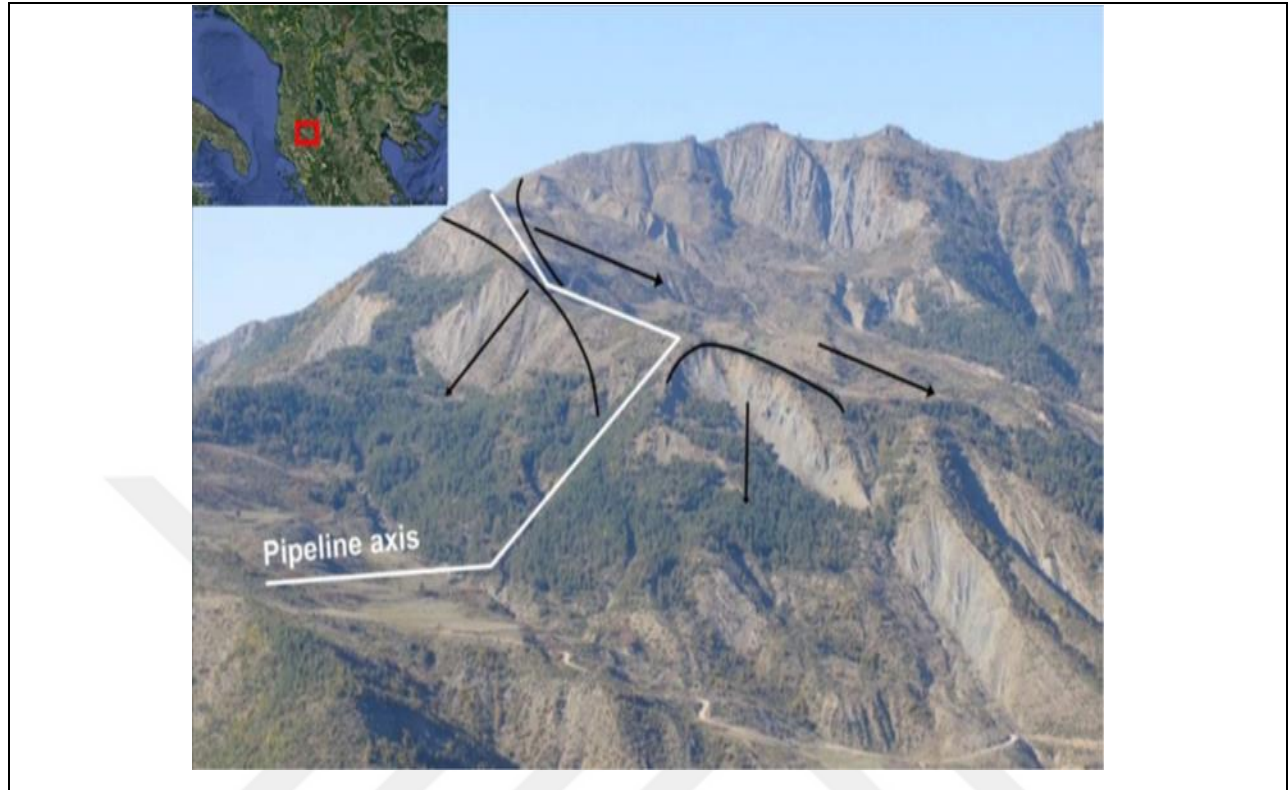


Figure 2.7: Pre-Existing Landslides (Black Lines) Along Trans Adriatic Pipeline (TAP) Pipeline Right of Way (RoW) in a Mountainous Region of Central Albania[27]



Figure 2.8: Diagram TAP Route of Study Area[27].

In light of the most up-to-date analysis of landslide and slope stability data available at that time for each of the route's 82 landslide locations. It's impossible to prevent landslides on TAP's route across steep terrain subject to significant seismicity, severe rainfall, and snow melt. As per worldwide best practice, landslide features were recognized and avoided by routing along ridge crests and spurs and minimizing exposure to potentially unstable, steep side slopes.

On ridge flanks and slopes that are considered at risk of failure due to their rough topography, there have been known landslides within 50 meters of this route. This means that removing all danger of landslides has been impossible. The steep hill slopes between 77 and 90 kilometers along the TAP route still risk new landslides under static or seismic circumstances. Unforeseen landslide threats might exist throughout the project's development and operating stages. Some geohazard specialists from different institutions and firms engaged in the project were invited to participate in an informal meeting. They shared their thoughts and concerns about potential exposure to "pre-existing" landslide locations along the route. An increasing number of continuing landslides is projected to lead to the loss of the ridge and the bursting of pipelines. The risk (i.e., the chance of a pipeline rupture) at 82 locations was assessed using a qualitative 5-class probability scale. One hundred and nineteen (19) of the landslides were classified as "Low Risk," while the remaining landslides were classified as "None" or "Negligible."

Raffaele De Risi et al. [28] The danger presented by gas pipeline infrastructure after a large-scale regional earthquake should be assessed, Simulation-based methods may be used to estimate seismic intensity measurements (IMs), such as PGA and PGV, at each pipe in a network once earthquake data like as magnitude and epicenter have been identified. Real-time updates from accelerometer stations are being investigated.. A hybrid empirical-mechanical-based assessment of permanent ground displacements is then utilized to assess the hazard of cascading landslides and liquefaction, among other uses, for these IMs to be implemented in the following stages (PGD). In order to help network managers and other stakeholders make informed decisions, damage and fragility functions drawn from the scientific literature are used to provide loss statistics and damage maps.

Prioritizing post-incident inspections is made easier by the use of damage maps and losses, which offer an estimate of restoration costs. Innovative and tried-and-tested methodologies are combined in the risk methodology. First, the numerous PGA and PGV cross correlation models are given in order of appearance. Another geotechnical approach for both landslides and the assessment of liquefaction PGD has been presented, which represents (1) susceptibility (2) triggering and (3) PGD estimating steps. As a test-bed scenario for the risk approach, the 1976 Friuli earthquake and northeast Italy's high-pressure gas network are used in order to emphasize the benefits and drawbacks of the several potential alternatives researched Fig. 2.9 visually displays the framework proposed in this research, which includes the methodologies for analyzing network threats.

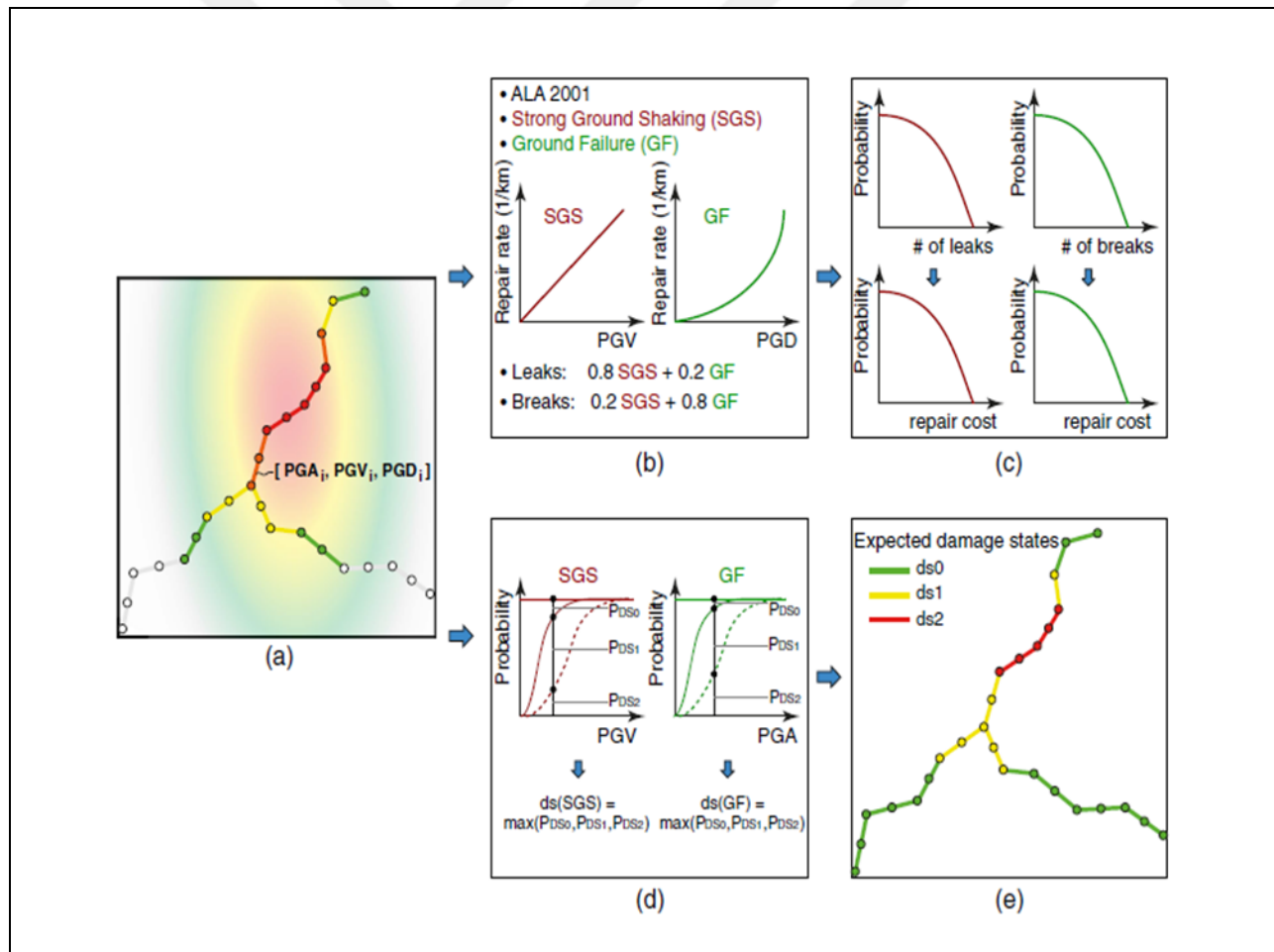


Figure 2.9: Seismic Risk Assessment[28].

Natural gas pipeline networks are more likely to be damaged by earthquakes if the intensity measures used to assess their seismic risk are correlated and cross-correlated rather than simply spatially correlated or uncorrelated. If available after the earthquake, real-time updating of the intensity measure fields from accelerometric data can be used to avoid underestimation of losses. In the case of damage to infrastructure stakeholders as a consequence of an earthquake, the process outlined above breaks down the costs and kinds of actions necessary; and In addition, this technology generates maps that show where the projected damage is located, making it simpler to conduct inspections and lowering the time it takes to recover after an earthquake.

Marchesini et al. in [29] investigated the relevance of the risk of pipeline rupture caused or largely caused by landslides, which the pipeline sector is increasingly aware of. Landslides that compromise a pipeline's integrity are uncommon, but they usually have more serious consequences than other pipeline hazards (such as corrosion and stress corrosion cracking). Landslide-related strain in pipelines can be induced by a quick occurrence, such as a debris flow, or by slow, continuous movements, such as creep. Understanding the risks and being able to react to a failure before it causes a rupture is the ultimate goal in pipeline risk assessment and management. A successful strategy to achieve this goal is to correctly identify places that may pose a geohazard, visually check these sites, and develop a cycle of site assessment and management techniques based on the site inspections to address the risk. The cyclic assessment should be dynamic, describing and determining current risk circumstances at all times.

When slow-moving landslides occur, a review can be arranged so that mitigation can take place before the pipeline ruptures. These risk assessments should be integrated into a pipeline integrity management system that allows for the evaluation of all pipeline hazards. A landslide can be controlled in this situation; however, it is crucial to remember that this is a continuous process that must be maintained in order to be effective. The cyclic process of hazard evaluation, which begins after hazard identification, provides for continuous updating of the risk posed by a specific site based on the most recent visual observations. Because information gained from any of the recommended activities, save site removal, influences the risk assessment of that site, it influences the risk estimation of that site.

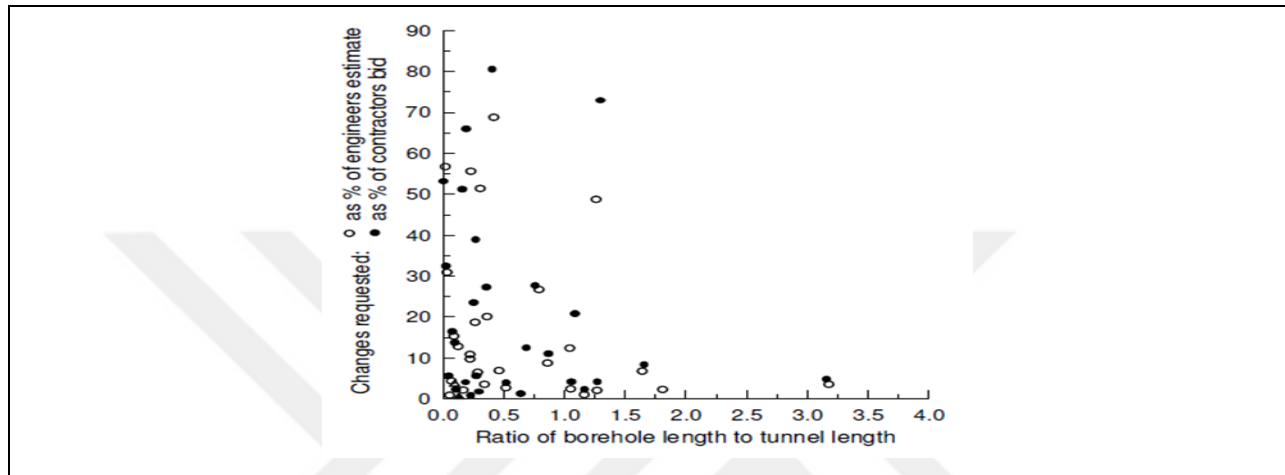
2.2.3 Geotechnical Risks in Infrastructure Civil Engineering Projects

Sandip Deb et al. in [30] present an overview of the threats posed by ground, based on real-life experiences. The impact of geotechnical risk is generally understood by most ground engineering practitioners, but other construction professionals typically misunderstand or undervalue the problem and measures for mitigation. The major goal of this study is to reduce geotechnical risk. Because geotechnical risk management is not integrated into overall project risk management, the construction industry is missing out on possibilities to reduce ground-related failures. The insights derived from their in-depth investigation allow them to improve the structure's safety in an attempt to minimize risk to "as low as reasonably practicable."

Polyankin et al. in [31] The surrounding structures, topography, engineering-geological, and hydrogeological elements of the construction site area were analyzed as possible geotechnical hazards that might affect the occurrence of crises during the construction of subterranean projects. While geotechnical problems are frequently overlooked while cities' subterranean areas are being constructed, this is an undeniable truth. There is no complete risk management method for the design of complex multifunctional facilities. A geotechnical risk management system was established during the building of Moscow's Sheremetyevo Airport's Inter-terminal transition beneath the runways. This method has been shown to reduce the risk of construction-related injuries and fatalities. According to a report, geophysical inspections of the runway foundation; filling gaps before sinking beneath the runway; exploratory drilling and geophysical surveys before sinking dangerous regions were among the suggestions produced to lower the amount of risk at the evaluated facility. As a result of their findings concluded that any approach for measuring total risk throughout the design, building, and operation of an underground facility may considerably lower the likelihood of abnormal and emergency circumstances. Sheremetyevo Airport's inter-terminal transition beneath the runways may be lowered greatly or eliminated by early reaction to developing dangers, high-quality construction and installation activities, and further precautions, according to research done during construction.

Evert Hoek et al. in [32] examine methods for predicting geological conditions. According to research, Cost and schedule overruns in big civil engineering projects are often caused by unforeseen geological conditions and related geotechnical concerns. The problems persist despite repeated attempts to remedy them by putting various terms into contract papers. To avoid

unpleasant surprises, it is best to characterize the geological conditions as early as feasible. Figure 2.10 is based on interviews with 84 tunnel owners, engineers, and contractors conducted by the United States National Committee on Tunnel Technology (USNCTT). This graph shows cost variations as a function of the ratio of exploration drill length to tunnel length.



under discussion for mitigating difficulties created by unexpected geological situations is a Geotechnical Baseline Report and Risk Sharing Packages.

Kerim Koc et al. in [3] analyzed to determine the financial and scheduling impact of geotechnical hazards. Accordingly, a literature review was undertaken to estimate the CII, SII, and FI of geotechnical concerns, which were then utilized to quantify the relevance of each risk category. In Turkey, A survey was carried out with the participation of 47 heavy civil construction industry experts. The cost and schedule of each risk were calculated using the significance index theory. A correlation analysis was used to see how respondents differed in their estimations of cost and timeliness. Figure 2.11 shows the cost and schedule effect of each risk factor. According to the data, there is a connection between the effect of risk, the cost, and the schedule. According to the means influence on cost and schedule, all geotechnical risk factors have a low likelihood.

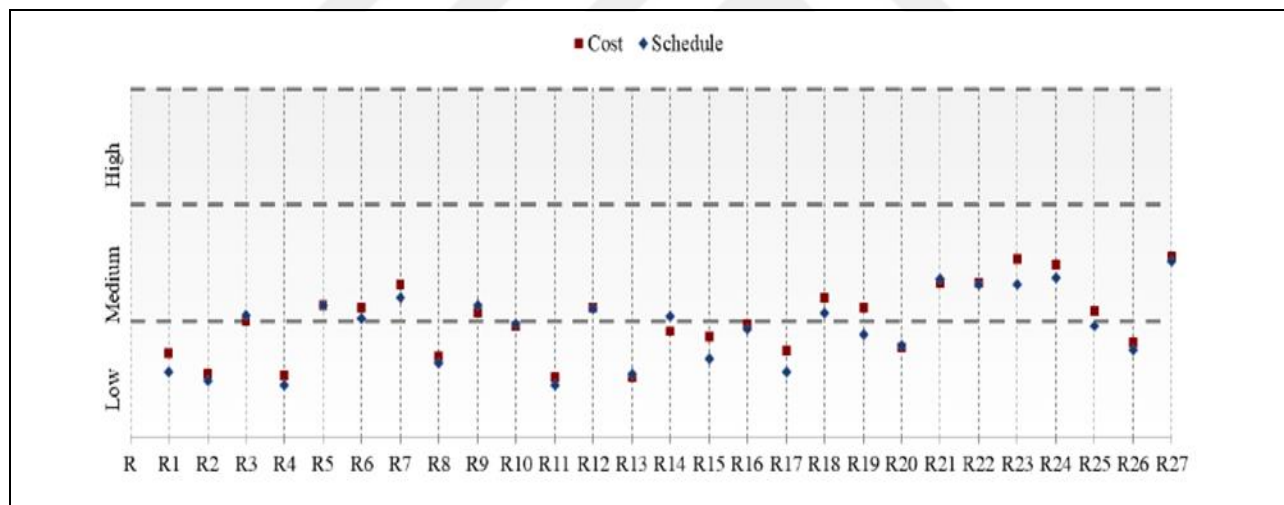


Figure 2.11: Cost and Schedule Impacts of Risk Factors [3].

They determined that slope instability is the most expensive and time-consuming geotechnical risk in infrastructure projects, with soft compressible soil being the most common hazard. "Soft clays, organic silts, or peat" were the most significant when both impact and frequency were considered. According to the findings, respondents' perceptions of the influence of geotechnical risks on time and cost are similar. More advanced technologies will be used to categorize and analyze geotechnical concerns in comparison to previous research. Professionals from other

countries might be included in the survey. Research like this may help those looking for the underlying geotechnical causes of costly and time-consuming project delays.



3. METHODOLOGY

Project risk management is a rapidly expanding field with applications across the engineering spectrum. Due to the high risks and uncertainties inherent in geotechnical engineering, risk management techniques are increasingly being used in infrastructure projects with the goal of gaining information of the main sources of uncertainty influencing cost and/or time. Project risk management is concerned with how to deal with hazards in the context of a project and during its execution. The ultimate goal of project risk management is to identify, mitigate, or capitalize on risks before they materialize. Understanding the risk, dangers, and uncertainties involved in a project is critical to its success. The risk distribution among the project's participants will also have a substantial impact on the project's performance. As a result, the chapter contains a review of the literature on risks, hazards, and uncertainties in geotechnical engineering, as well as risk sharing and risk management strategies in geotechnical engineering. The purpose of this chapter is to describe a system technique for recognizing and evaluating the risks associated with infrastructure projects. To detect geotechnical risks in infrastructure projects, a literature review was done. Because identifying ground conditions is more challenging in infrastructure projects than in normal projects, they take place in more unknown situations. The geotechnical risks selected from prior studies will be presented in the next section.

3.1 INFRASTRUCTURE RISK FACTORS

To detect geotechnical risks in infrastructure projects, a literature review was done. The risk factors discovered in the study by Douglas et al. in [1] were adopted in this research since it covered a large body of literature on the subject and presented a holistic view of geotechnical concerns rather than focusing on individual ones. Experts have characterized and tested the 27 risk factors identified by Kerim Koc et al. in [3] in order to specify the appropriate risk factors for use in infrastructure projects in Iraq's south. The next phase in this research is to use experts to determine the hazards associated with transportation projects. A complete list of 27 risk indicators was compiled based on a literature research, and a questionnaire was created to get feedback from specialists overseeing various infrastructure projects in Iraq. These risk factors are shown in Table 3.1.

Table 3.1: Geotechnical Risk Factors (From Kerim Koc et al.[3])

R1 - Settlement in general
R 2- Sensitiveness of Landscape
R 3- There are buried traces
R4 - The presence of cemeteries as a result of wars
R 5-Existing structures likely to be impacted by the work
R 6-Existing Contaminated material
R 7- construction waste dump
R 8- Landfill
R 9-Underground artificial debris
R10- Groundwater infiltration
R11- Soft compressible soil
R12- Groundwater/water table
R13- Soft clays, organic silts, or peat
R14- Highly compressive soils

Each risk factor's financial and scheduling ramifications. The elements suggest that the Iraqi environment in the south and the Iraqi environment in the north are linked. Sub-sections for each risk aspect offer the significance index based on cost and schedule. There are fewer gaps between soil particles when soil consolidation occurs due to applied pressures or changes in moisture content. Soils become more compact as they lose water. When moisture is discharged, the soil loses volume and condenses. Moisture in the soil causes more minor clays and silts, formerly employed to fill spaces between more extensive soil types and offer extra structural support, to flow down into the ground. It will also hurt the soil's ability to hold weight. Landscape sensitivity is a measure of a landscape's resilience, or robustness, to endure specified change caused by Without causing significant harm to the landscape or visual baseline, many forms of development or land management approaches may be used, as well as their worth –

such as changes to valued baseline landscape character and visual resource attributes. Landscape sensitivity evaluation is a method that evaluates the resilience / robustness of landscape character, visual resource, and what we value in the face of a specific change or changes. It can assist decision-makers in comprehending likely changes and the sort of change that may occur as a result of specific courses of action, such as development or land management scenarios. The type of soil used around the foundation has a significant impact. Clay soil, for example, is dense and reacts fast to water, swelling and contracting like a sponge. Loam and sandy soils, on the other hand, drain better and compress and expand less than expansive soils. It's perhaps possible that the architecture of your home was not fitted to the sort of soil beneath it. Another influence is the moisture content of the soil. The earth is drier near the foundation's perimeter. Too much moisture, on the other hand, softens and weakens soil. The water leak will soften the soil along the foundation's footing, causing the foundation to slump. Hydrostatic pressure occurs when the soil is excessively dry or too moist, depending on the nature of the soil[33][34].

Plants and trees in close proximity to the project have the potential to induce settling. Tree roots, in particular, will draw moisture from the earth. This is particularly common during droughts and extended periods of dry weather. When the weather is dry, the soil shrinks. The most common reason is tree roots, which are continually looking for water and will steadily develop around and under the foundation. Soil dryness is mostly a problem with shallow foundations that are closer to the surface. Because basement-level foundations reach deep into the ground, these structures are more subject to ground movement. [35].

3.2 DELPHI METHOD - RANKING THE CRITICAL SUCCESS FACTORS

One of the study's key goals is to rank the most relevant critical risk variables for infrastructure projects. The ranking must be carried out by an expert team. The Delphi approach provides a versatile and adaptive instrument for collecting and analyzing data for the researcher. For the following reasons, the Delphi approach is used[36][37]:

- a) Although precise analytical procedures are not appropriate for this topic, aggregate subjective judgments can help.
- b) In terms of experience and competence, the people required come from a variety of backgrounds.

- c) Delphi is a qualitative technique for reaching group consensus without the drawbacks of face-to-face encounters, such as group conflict and individual dominance. The Delphi approach was chosen for a number of reasons, one of which is that the expert panel consists primarily of decision makers.
- d) In the Delphi procedure, professionals express their opinions without openly admitting it, allowing them to convey a more personal perspective rather than a cautious institutional attitude.
- e) In order to ensure the validity of the results, the participants' heterogeneity must be retained, i.e., dominance by amount or by personality strength must be avoided.

Finally, Delphi is one of the most widely used forecasting methodologies for technological and industry-wide forecasting, with Delphi accounting for approximately 90% of technological forecasts and research.

Before beginning the inquiry, the Delphi technique was developed and applied with the selection of subjects and periods in mind. Aside from ensuring low response rates and inadvertently influencing input, additional protections include assessing panelists' lack of expertise rather than asking for their expert views [38].

As a result, the Delphi method for this study is as follows:

- a) Assemble a team to conduct and supervise a Delphi on a specific topic.
- b) Choose one or more panelists who are specialists in the field under investigation.
- c) Create the first Delphi round questionnaire.
- d) Double-check the questionnaire's language for accuracy.
- e) Gather data for the first questionnaire and distribute it to the panelists.
- f) Examine the first round responses and provide feedback to the panel members.
- g) Ask each panel member to score or rank the first questionnaire's outcome. This is the second round of the survey.

- h) Examine the responses from the second round.
- i) Describe the outcome of Questionnaire x. The analysis team will prepare a report to present the exercise's conclusions.

3.3 THE USED CRITERIA

Experts are qualified by their knowledge, skill, experience, training, or education; consequently, the following criteria were utilized to identify experts for this study:

- a) Awareness of local skills;
- b) Some knowledge of important success elements;
- c) Experience with and contribution to the local and other regions of the infrastructure field;

The specialists split the study area into sectors throughout Iraqi land due to the effectiveness of geotechnical hazards such as groundwater level and depths, regional trends in its flow, change in its specific quality (especially salinity), and its appropriateness for multifunctional. In Iraq, there have been 15 different types of geological hazards discovered. Despite the fact that they are poorly documented and kept, geological survey and mining (geological survey and mining) is a state-owned company (GEOSURV) [39] has created a series of 1: 250 000 scale geological hazard maps that cover the whole Iraqi territory in 39 quadrangles. A Geological Hazards Map of Iraq has also been prepared at a scale of 1: 1000 000. Each of these maps comes with a report that names, categorizes, and ranks the geological hazards that exist. Except for GEOSURV data, seismicity, and meteorological data, there are virtually no other geological hazards data available in Iraq , as illustrated in Figures 3.1 and 3.2.[40][41][42].

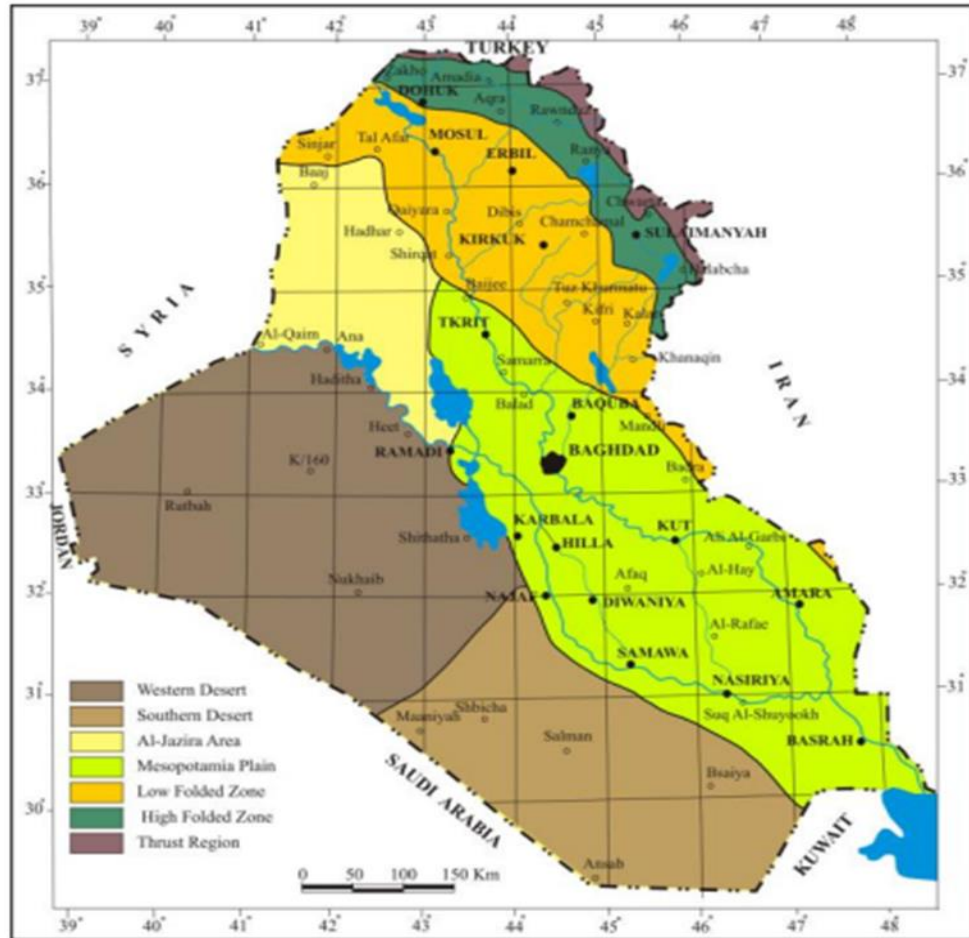


Figure 3.1: Physiographic provinces, exhibiting different types of geological hazards (Varoujan K. Sissakian et al, 2011)

Iraq is divided into 39 quadrangles with a size of 1: 250 000; from 1992 to 2009, GEOSURV published geological maps with the same scale, based on geological maps with a resolution of 1: 100 000. The 1: 250 000 scale Geological Hazard Maps were compiled mostly from GEOSURV's published Geological Maps at 1: 250 000 scale (1992–2009). The collected maps that cover the entire Iraqi area are only displayed in 35 sheets since some quadrangles are linked with their nearby quadrangles on one sheet.

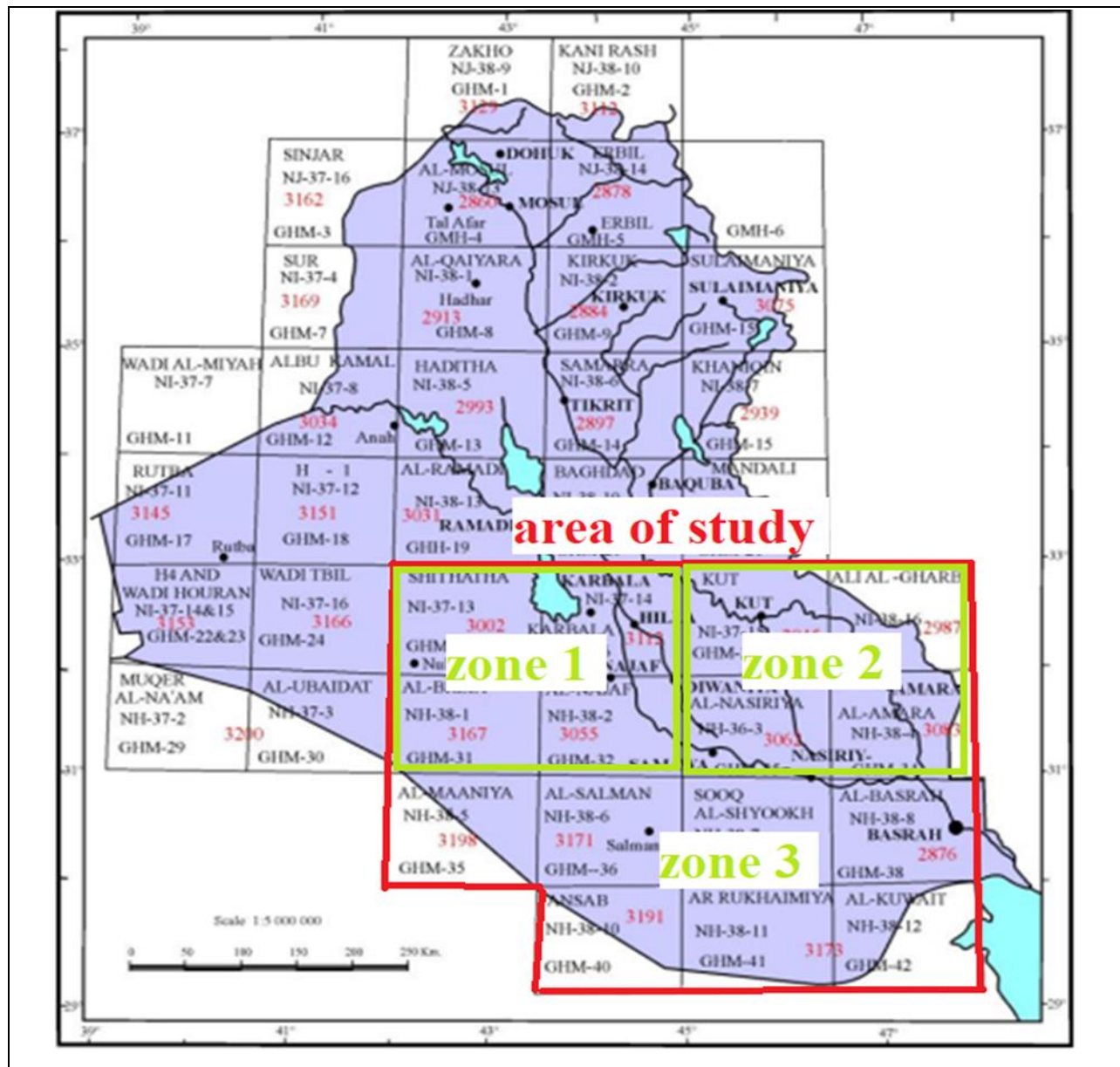


Figure 3.2: Geological Hazard Map Quadrangles (Varoujan K. Sissakian et al, 2011)

Each region's characteristics were addressed independently, including particular aspects relating to groundwater recharge, quality groundwater flow, hydraulic characteristics of groundwater aquifers, groundwater sector concerns, and the creation of recommendations. Iraq was split into seven zones from a hydrogeological standpoint, based on physiological, structural, geological, and hydrogeological properties. The hydrogeological and hydrochemical properties of each zone are distinct[40][43][44]. As seen in Figure 3.3, these zones can be concisely characterized as follows:

- a) The Mesopotamian Foredeep is the first level of the Mesopotamian pyramid system (Mesopotamian)
- b) Folded Low Zone
- c) Zone of High Folds
- d) Thrust Zone and Suture
- e) Zone of Al-Jazira
- f) Zone of the Western Desert

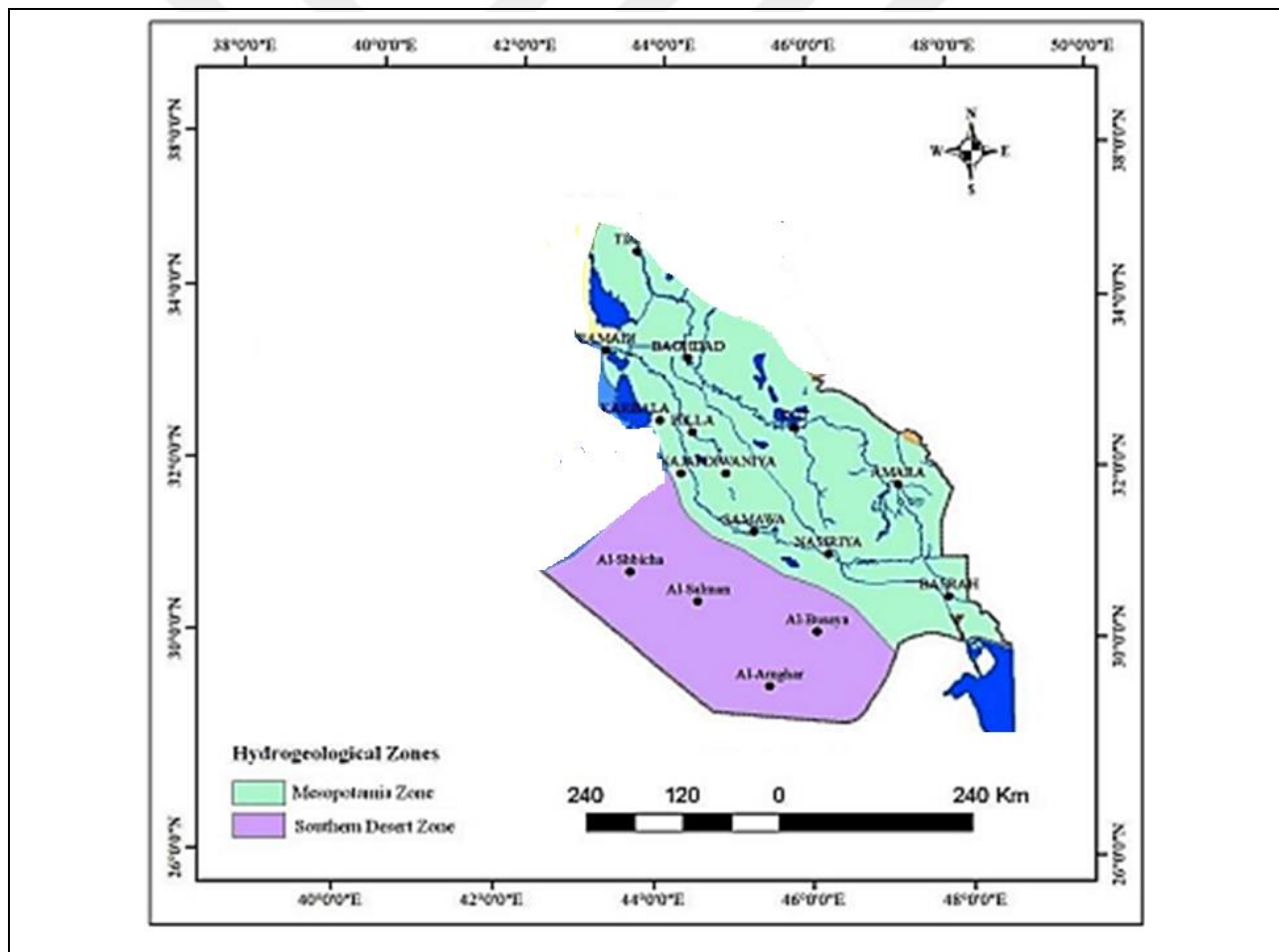


Figure 3.3: The main hydrogeological zones in south of Iraq (Sabbar A. Saleh et al, 2020)

While Iraq's groundwater aquifers are separated into many primary hydrogeological units, as shown in Figure 3.4:

- a) The Foothill Aquifer System is one of the most important aquifer systems in the United States.
- b) The Aquifer System of Al-Jazira.
- c) The Mandali-Badra-Teeb Aquifer System is a system that consists of three aquifers: Mandali, Badra, and Teeb.
- d) The Mesopotamian Aquifer System is a system of aquifers in Mesopotamia.
- e) The Desert Aquifer System, which is divided into two subsystems, the northern and southern aquifers.

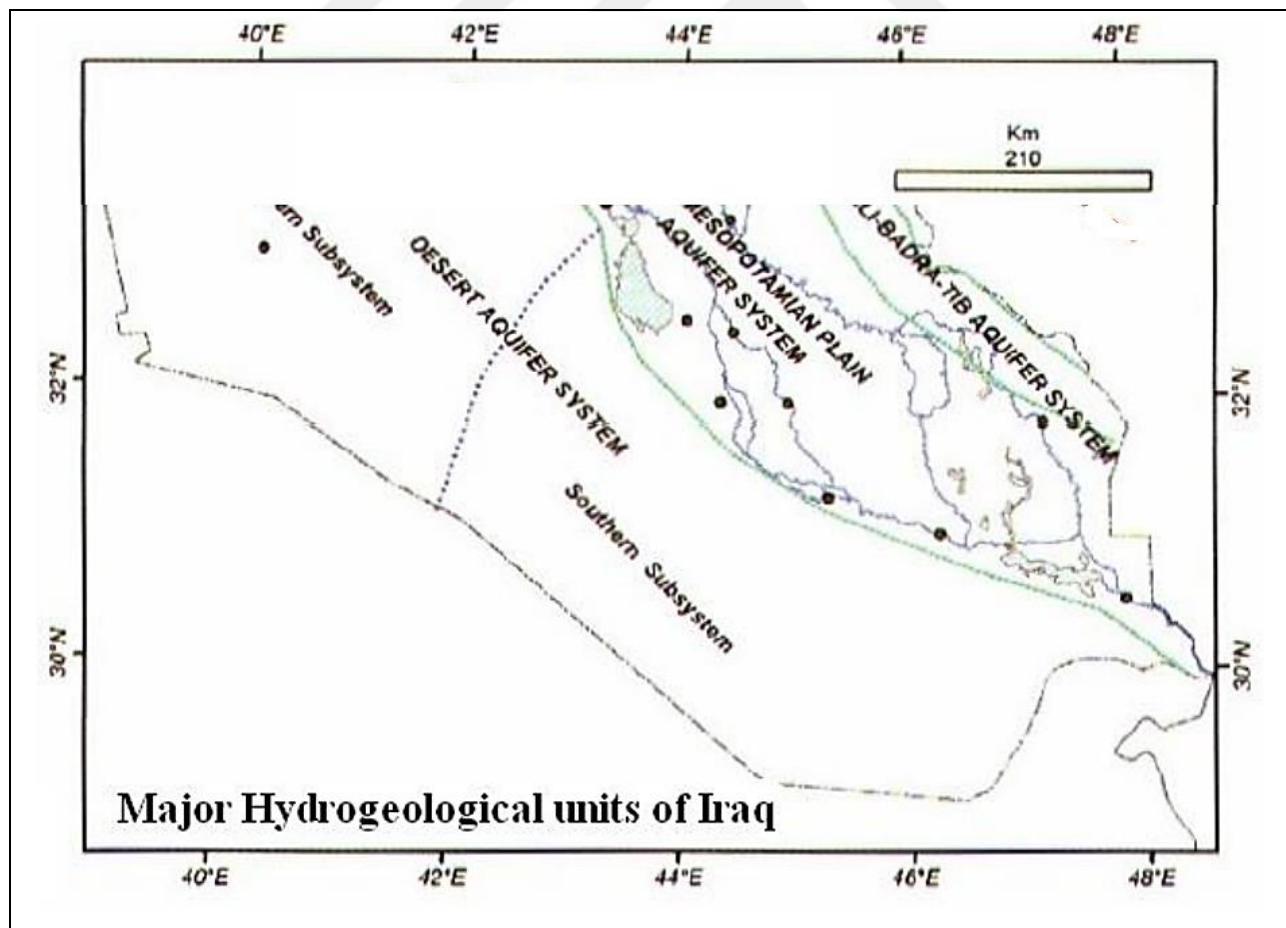


Figure 3.4: The Main Hydrogeological Systems in South of Iraq (Sabbar A. Saleh et al, 2020)

There are a total of 14 risks identified that were divided into three specific categories, as shown in Table 3.2.

Table 3.2: The Region Ranks

		Egion rank					
		zone 1		zone 2		zone 3	
		ranking impact	ranking frequency	ranking impact	ranking frequency	ranking impact	ranking frequency
group 1	R1 - Settlement of adjacent structure						
	R2- Sensitiveness of public consideration						
	R3- There are buried traces						
	R4 - The presence of cemeteries as a result of wars						
	R 5-Existing structures likely to be impacted by the work						
group 2	R 6-Existing Contaminated material						
	R 7- construction waste dump						
	R 8- Landfill						
	R 9-Underground artificial debris						
group 3	R10- Groundwater infiltration						
	R11- Soft compressible soil						
	R12- Groundwater/water table						
	R13- Soft clays, organic silts, or peat						
	R14- Highly compressive soils						

The questionnaire was designed to establish how frequently the risks mentioned in this study happened during infrastructure projects; and The consequences of the listed dangers The survey questionnaire was used to obtain data that aided in understanding the practitioners' perceptions of risk factors. Experts working on Iraqi initiatives were the target responders. On a scale of 0 to 5, they were asked to rate the hazards. The scale was chosen to allow for more freedom in selecting statistical procedures, with a rank of 0 indicating a risk with no substantial contribution to frequency and impact and a rank of 5 indicating the risk with the greatest contribution[45][46].

Table 3.4: The Questionnaire of The First Group Risks

group1						
	statement	strongly disagree	disagree	neutral	agree	strongly agree
No.	SCALE VALUE	1	2	3	4	5
1	There are old structures in or adjacent to the work area that may affect the excavation work					
2	Excavation works and negation of the project affects public parks and causes confusion and obstruction of citizens					
3	The project implementation area may contain buried antiquities					
4	The excavation area may contain graves and war relics					
5	Neighboring work structures will be affected by the project work					

Table 3.5: The Questionnaire of the Second Group Risks

	group2					
	statement	strongly disagree	disagree	neutral	agree	strongly agree
No.	SCALE VALUE	1	2	3	4	5
1	There are polluting materials buried in the work area					
2	The area was a dump					
3	The area is buried with building waste					
4	The area is buried with the waste of nearby factories					

Table 3.6: The Questionnaire of the Third Group Risks

	group3					
	statement	strongly disagree	disagree	neutral	agree	strongly agree
No.	SCALE VALUE	1	2	3	4	5
1	In the project area there is underground water seepage					
2	Compressible soft soil					
3	The groundwater level is high					
4	The project area contains fine clay, organic silt or peat					
5	highly compressed soil					

3.3 SOFTWARE MATLAB R2018A

As a Matlab -paradigm numerical computing environment and fourth-generation programming language, MATLAB was used in this work. When working with MATLAB, you may perform operations on matrices and functions, create user interfaces, implement algorithms, and communicate with programs written in other languages, including C, C++, Java, FORTRAN, and Python. Control engineering was the first field to utilize MATLAB, but it quickly spread to several other areas. It is now widely used in education, especially in the teaching of linear algebra and numerical analysis and among image processing professionals. In MATLAB, structure data types are provided. Because all variables in MATLAB are arrays, the term

"structural array" is a better fit, as each array element has the same field name. MATLAB also contains several tools for documenting and sharing user work and dynamic fields. MATLAB methods and applications can be distributed, and MATLAB code can be combined with other languages and applications. To determine the things that have an impact:

```

1  clc;clear ;close all
2
3  %%%%%%%%%% THIS CODE BUILT FOR EVALUATING %%%%%%%%%%
4  %%%%%%%%%% THE RISKS IN INFRASTRUCTURE %%%%%%%%%%
5  %%%%%%%%%% GEOTECHNICAL IN IRAQ %%%%%%%%%%
6  %%%%%%%%%% IN THE SOUTH REGION ONLY %%%%%%%%%%
7  disp('=====');
8  disp('=====');
9  disp('EVALUATE THE INFRASTRUCTUR PROJECT ');
10 disp(' BASED ON RISKS ');
11 disp('==== influence factors of infrastructure project ====');
12 disp('=====');
13 prompt = "what is the region? ";% zone 1, zone 2, zone 3
14 region_of_study = input(prompt);
15
16 %%%%%%%%%%
17

```

Figure 3.5: MATLAB Code

3.4 HIERARCHY PROCESS FOR ANALYSIS

The literature offers several systematic ways to assess risk management in building projects. According to Kangary and Riggs (1989), these techniques may be divided into two categories: classical models (which include probability analysis) and conceptual models (which include other approaches) (i.e. fuzzy set analysis). They uncovered two fundamental weaknesses in probability set models. Some models need speculative quantitative data, which is frequently unavailable at the early stages of development or planning. As a result, risk analysis is limited in this approach. As a result, project risk assessment must take a subjective approach. Saaty developed the analytical hierarchy technique (1980). In project risk analysis, it allows for the utilization of both objective and subjective factors. The reasoning problem is formulated using the first phase of a hierarchy structure. The main goal of the choice problem is depicted at the highest level of a traditional hierarchy. The factors at the intermediate level have an impact on

judgment. The decision option represents the lowest level. The decision makers carefully assess the hierarchy's numerous components after it has been formed, Two at a time, comparing their influence on a higher-ranking factor. Data may be used to establish comparisons by decision makers, but they mostly depend on their views of the relative importance and worth of the parts. The AHP is based on the premise that evaluations can be done using human judgments rather than only the underlying data. Because the elements are normalized eigenvectors associated with the comparison matrix's largest Eigenvalue, A comparison matrix is used to discover which aspects of each level are more important when compared to those in the subsequent level. It is possible to achieve this goal by working down a hierarchical ladder from highest to lowest level, doubling your weights as you go. [47][48][49].

3.4.1 Prioritizing and Synthesizing Hierarchy

Priorities are obtained from judgment and synthesized down the hierarchy by a weighing and assembly technique, which progresses from local priorities derived from multiplying the criterion's importance to overall priorities derived by assembling the global priorities of the same element. The consistency of the paired judgments is represented by this consistency ratio.

3.4.2 Priority Vector Calculation

Step 1: We begin by preparing a typical matrix. For each comparison matrix, the technique of preparing a standard matrix is to add up the columns and divide each column value by column summation[50].

$$f(\lambda) = |A - \lambda I| = \begin{vmatrix} a_{11} - \lambda & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} - \lambda & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n1} & a_{n1} & a_{nn} - \lambda \end{vmatrix} \quad (1)$$

Step 2: Next, we computed the average of each row, which is referred to as the priority vector. Each column and non-zero vector X_i are the eigenvectors of matrix A [from Equation (2)], for which the following equality holds :

$$(A - \lambda_i)X_i = 0 \quad (2)$$

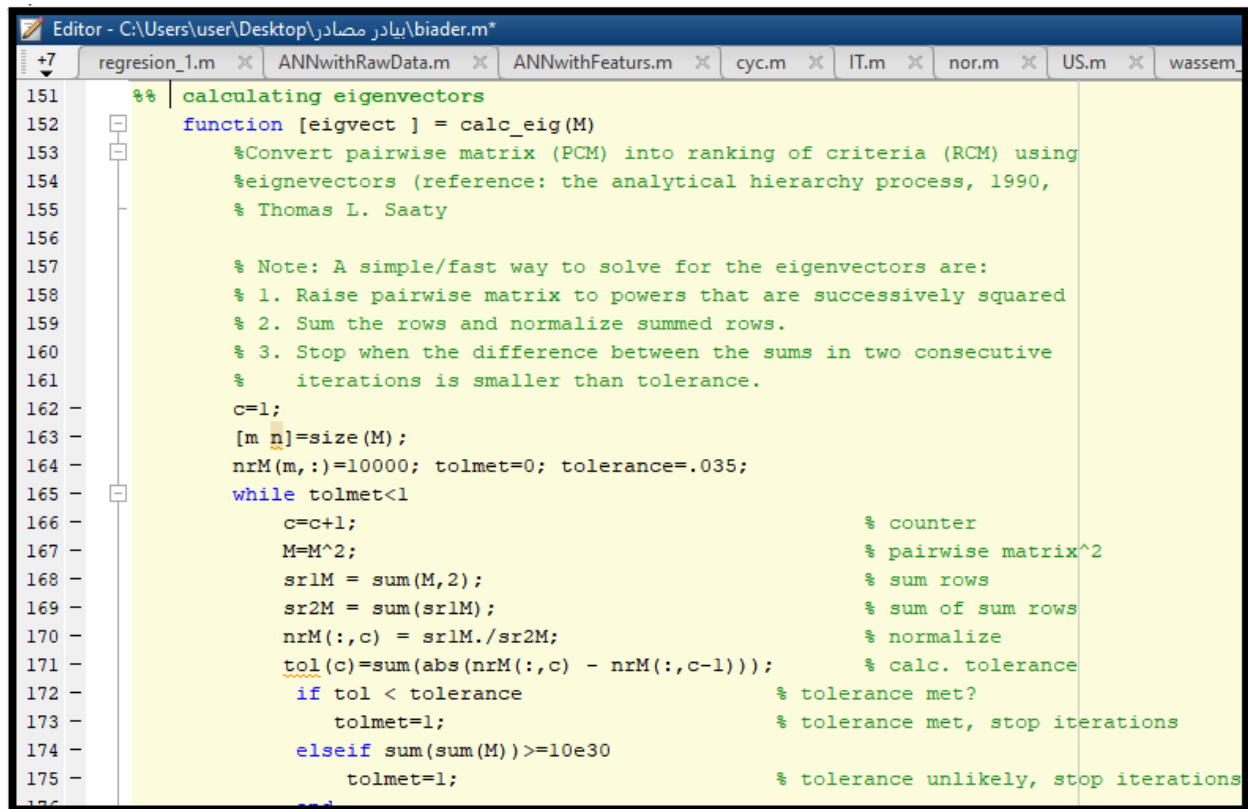
$$AW = \lambda_{\max}W \quad (3)$$

Step 3: Multiply the priority vector by the standard matrix, then add all of the column's values together and take the average.

Equation may be used to get the maximum eigenvector max (4). Here, n is the number of elements, and w is the matrix of weights.

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^n \frac{(Aw)_i}{w_i} \quad (4)$$

The MATLAB code for this step shown below:



```

151 %% calculating eigenvectors
152 function [eigvect ] = calc_eig(M)
153     %Convert pairwise matrix (PCM) into ranking of criteria (RCM) using
154     %eigenvectors (reference: the analytical hierarchy process, 1990,
155     % Thomas L. Saaty
156
157     % Note: A simple/fast way to solve for the eigenvectors are:
158     % 1. Raise pairwise matrix to powers that are successively squared
159     % 2. Sum the rows and normalize summed rows.
160     % 3. Stop when the difference between the sums in two consecutive
161     % iterations is smaller than tolerance.
162     c=1;
163     [m n]=size(M);
164     nrM(m,:)=10000; tolmet=0; tolerance=.035;
165     while tolmet<1
166         c=c+1; % counter
167         M=M^2; % pairwise matrix^2
168         srlM = sum(M,2); % sum rows
169         sr2M = sum(srlM); % sum of sum rows
170         nrM(:,c) = srlM./sr2M; % normalize
171         tol(c)=sum(abs(nrM(:,c) - nrM(:,c-1))); % calc. tolerance
172         if tol < tolerance % tolerance met?
173             tolmet=1; % tolerance met, stop iterations
174         elseif sum(sum(M))>=10e30
175             tolmet=1; % tolerance unlikely, stop iterations
176     end

```

Figure 3.6: AHP MATLAB Code

3.5 RELATIVE IMPORTANT INDEX (RII)

Decisions made throughout the risk management process are influenced not just by the extent or severity of the risk, but also by the decision-makers' risk tolerance. As a result, once the risks have been evaluated, it is necessary to determine if they are acceptable or not. The degree of risk that a person, a customer, or society is ready to accept influences the choice that a decision-maker is willing to make. It's important to consider all aspects of the project before making any judgments concerning time and money, as well as technological solutions, and so on, it's critical to establish the acceptable risk threshold. The acceptable risk level must be defined early in the project in order to make the best decisions possible throughout the beginning phases. The project's risk policy should specify the acceptable risk threshold. Risk acceptance is determined by a decision-willingness maker's to accept a given risk. Risk acceptance is influenced by a number of elements, including the individual's or organization's risk perception, decision criteria,

and prior knowledge and experience with similar decision scenarios. The actual treatment of a risk by an individual or an organization displays risk acceptance, which can be classified into three categories: risk averse, risk neutral, or risk taking (see Figure 3.7). The certainty equivalent, which is the expected value or the assured amount of resources that is similarly valuable as a risky circumstance, can be used to characterize these[51][52].

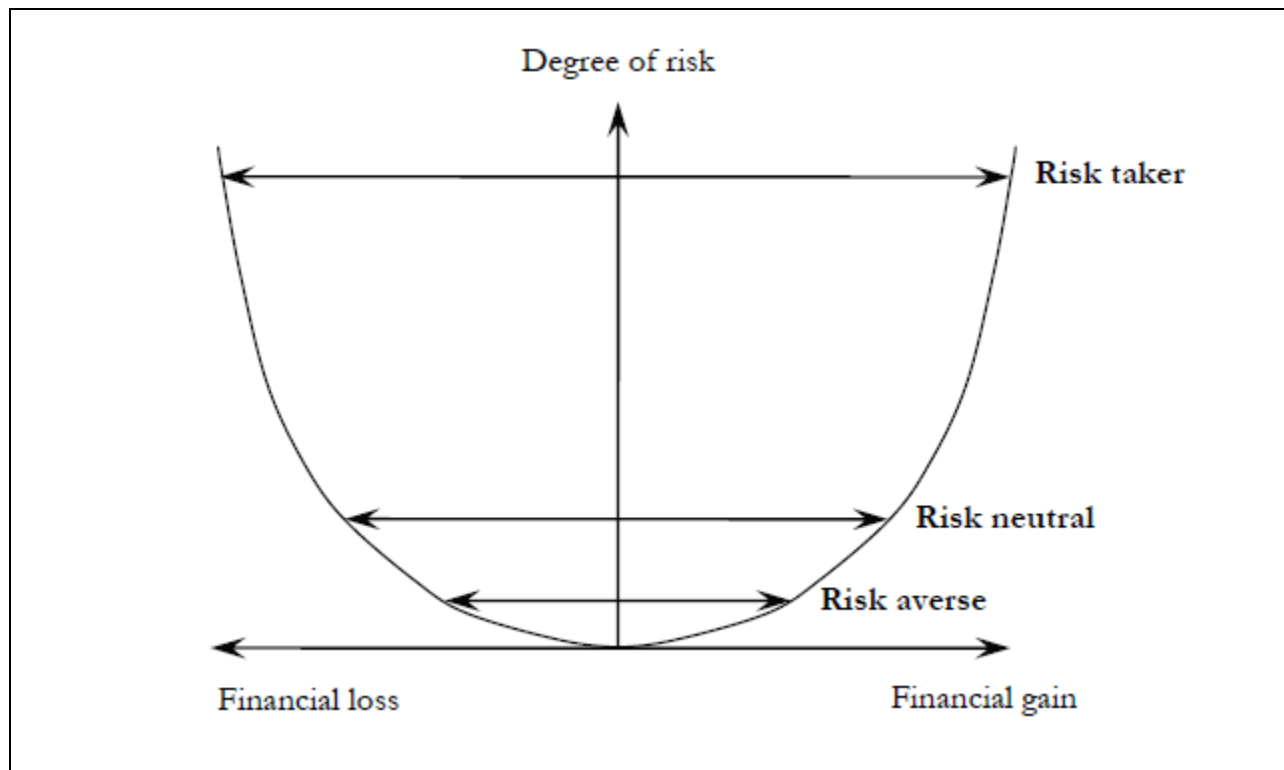


Figure 3.7: Risk Acceptance for Different Types of Decision-Makers [31]

Risk acceptance is influenced by a variety of things. Furthermore, the acceptable risk level varies among individuals, groups, and nations, and is influenced by a variety of elements including personal, technological, economic, social, and psychological aspects. Risk acceptance is determined by a variety of factors, including previous risk situations, public attention, familiarity with the working procedures, and so on. Individuals' risk tolerance is frequently risk adverse, whereas project managers' risk tolerance is risk neutral or even risk taking. In general, individuals' risk perceptions appear to follow a Gaussian distribution with skewness towards a lesser willingness to accept risks, implying that humans are risk averse by nature. When the sacrifice or expected loss is minor, risk neutrality can be assumed. In most cases, however, determining an individual's or an organization's risk tolerance is nearly impossible. As a result,

accepted risk thresholds must be determined using more basic procedures. To determine the acceptable risk level, conduct a cost-benefit analysis. The goal is to maximize the difference between the project's overall benefit and the project's total cost. One parameter of the overall cost is then the probability and consequence of failure.

The RII test on survey responses is primarily used to identify the influence of risk variables by giving a risk value to each variable. The purpose of this study's analysis was to identify the relative relevance of the several variables listed as being important for the effective completion of infrastructure projects. To calculate the score for each factor, the sum of the respondents' scores is used. RII was calculated using the equation below. (Nguyen et al, 2014):

$$RII = \sum (P_i U_i) / Nn$$

RII = relative importance index

P_i = respondent's rating of risk

U_i = number of respondents placing identical weighting/rating on the risk

N = sample size people responded to the survey

n = the highest attainable score for each risk

Contractor-related, owner-related, designer-related, and project management team-related risks were all ranked using the equation above. The RII is also used to establish the frequency and impact rating of the risk based on the survey data.

The syntax of MATLAB:

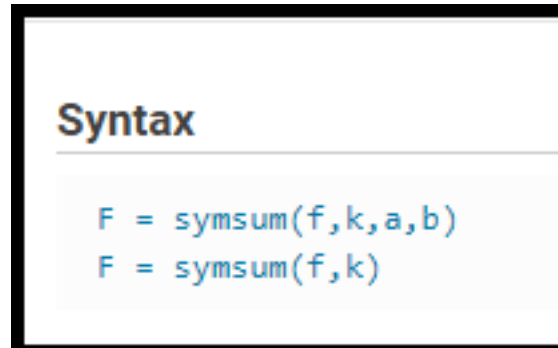


Figure 3.8: MATLAB Syntax

The risk decision is the correlation between the risk factors which is evaluated in this thesis based on region and zone, priority factor which is calculated from AHP method and the project influence factors.

Table 3.7: The Influence Factors

	influence factors on infrastructure project	
1	underground depth of the project	0.91
2	urban region	0.82
3	Contaminated region	0.78
4	clay surface region	0.81
5	waste dump region	0.88
6	area size of project	0.62
7	type of machinery used	0.57

4. RESULTS AND DISCUSSION

The risk management process is subjective, and various risk analysts may arrive at different conclusions. As a result, it is critical that the process be properly documented. Furthermore, as with all other studies and investigations, it is crucial that the results be critically evaluated. Geotechnical risk checklists assist geoengineers in identifying and assessing the hazards associated with their projects. A building hole, pile foundation, garbage depot, pumping station, dike, and road all have their own checklists. During each project phase and within distinct geotechnical engineering disciplines, all conceivable bad occurrences and reasons are outlined for each type. The entire risk management process must be recorded in a logical and systematic manner as a basic need of quality assurance. This documentation serves as a final check to ensure that the analysis was completed correctly. The goal of the analysis, the techniques and data sources utilized in the analyses, the recommended risk management activities, and the major outcomes should all be included in the documentation. There are unquestionably significant benefits to articulating probability and consequence estimates with the precision that comes with a quantitative approach. However, if there are inconsistencies in data quality or data sources, a quantitative analysis isn't always the best option. In these cases, a well-conducted qualitative analysis with the same degree of information can be applied. Regardless of the method employed, the documentation should include a statement of the data quality and data sources employed in the analysis. Also included should be a description and discussion of the system and problem definition, identified risk sources and hazards, initiation events, and so on. This research provided a useful and effective tool for determining the importance of geotechnical risks. Risks are best controlled by the party with the best capabilities and credentials to manage them, according to a general guideline in risk management. As a result, certain risks can be assigned to a single party, protecting the project or preventing or avoiding the risks' consequences. The first stage in this chapter was to define the study area, which was the south of Iraq, and then the geotechnical risks were determined using the Delphi approach, based on related studies and expert opinions. The researcher estimated the RII of hazards based on the region zones in the second phase. The AHP was constructed using MATLAB software in the third step, and it examines the collected data to locate and evaluate hazards, as well as specify the rank of each

risk. The findings of the RII and the AHP can be compared. Finally, based on the risk assessment, the influencing variables of infrastructure projects were identified and tested.

4.1 DELPHI METHOD RESULTS

To determine the magnitude of the hazards, the percentage scoring approach previously outlined in this study was used. Identification requires a methodical approach to identify all risks correlated with infrastructure projects activities. The results regarding the top 14 most significant risks as shown in table 4.1.

Table 4.1: The Selected Geotechnical Risk Factors

No.	factor
1	R1 - Settlement of adjacent structure
2	R2- Sensitiveness of public consideration
3	R3- There are buried traces
4	R4 - The presence of cemeteries as a result of wars
5	R 5-Existing structures likely to be impacted by the work
6	R 6-Existing Contaminated material
7	R 7- construction waste dump
8	R 8- Landfill
9	R 9-Underground artificial debris
10	R10- Groundwater infiltration
11	R11- Soft compressible soil
12	R12- Groundwater/water table
13	R13- Soft clays, organic silts, or peat
14	R14- Highly compressive soils

4.1.1 The Effected Factors in Zone 1

Because of the diverse geotechnical features of these zones, the researcher divided the geotechnical hazards factor effect into three zones in this study. The first zone includes Al-najaf and Ad-diwaniah, which are both located in Saudi Arabia. A portion of it is agricultural, while the rest is a desert with numerous ancient monuments. The second region is Al-Amarah, which is distinguished by the presence of large bodies of water known as marshes. It contains only a few urban and archaeological locations. The city of Basra, as seen in Figure 4.1, is distinguished by the existence of huge muddy grounds as well as being a port overlooking the Arabian Gulf and possessing many urban buildings. As a result of zoning, we can better identify dangers. geotechnical risks change according to the geological structure and the nature of the land.



Figure 4.1: The Selected Zones in Iraq

Based on the expert's opinions, the working factors have been specified and the evaluation of each risk specified in the tables 4.2 to 4.4.

Table 4.2: The First Group of Selected Geotechnical Risk Factors in Zone 1

	factor	strongly agree	agree	neutral	Disagree	strongly Disagree
No.		5	4	3	2	1
1	R1 - Settlement of adjacent structure	2	4	8	3	3
2	R2- Sensitiveness of public consideration	8	4	4	3	1
3	R3- There are buried traces	5	5	3	4	3
4	R4 - The presence of cemeteries as a result of wars	7	5	3	3	2
5	R 5-Existing structures likely to be impacted by the work	7	6	3	2	2

Table 4.3: The Second Group of Selected Geotechnical Risk Factors in Zone 1

	factor	strongly agree	agree	neutral	Disagree	strongly Disagree
No.		5	4	3	2	1
1	R 6-Existing Contaminated material	6	4	4	3	3
2	R 7- construction waste dump	7	5	4	3	1
3	R 8- Landfill	6	5	3	4	2
4	R 9-Underground artificial debris	6	5	3	4	2

Table 4.4: The Third Group of Selected Geotechnical Risk Factors in Zone 1

	factor	strongly agree	agree	neutral	Disagree	strongly Disagree
No.		5	4	3	2	1
1	R10- Groundwater infiltration	8	5	3	3	1
2	R11- Soft compressible soil	7	5	4	3	1
3	R12- Groundwater/water table	5	6	2	4	3
4	R13- Soft clays, organic silts, or peat	6	7	3	2	2
5	R14- Highly compressive soils	7	7	3	2	1

For more information about the selected geotechnical risk factors in zone 2 and zone 3, see APPENDIX A.

4.2 RII RESULTS

Analyzing participants' replies to Likert-type scales may identify the majority of significant criteria, but it is also a valuable tool for selecting indications. Using a relative index analysis, we ordered the criteria based on their relative importance. The ranking results for each zone utilizing the relative index analysis are shown in the tables in the following sections. 14 threats were identified as having high importance levels in the risk assessment of infrastructure projects based on geotechnical effects as a result of these ranking results.

4.2.1 Zone 1 RII Findings

To identify risk variables in geotechnical infrastructure projects, the relative importance index, or RII, was calculated for each issue. These factors were ordered based on the derived RII values. .

Table 4.5: RII of Risk Factors Respond Scoring in Zone 1

factor	RII
R1 - Settlement of adjacent structure	0.59
R2- Sensitiveness of public consideration	0.75
R3- There are buried traces	0.65
R4 - The presence of cemeteries as a result of wars	0.72
R 5-Existing structures likely to be impacted by the work	0.74
R 6-Existing Contaminated material	0.67
R 7- construction waste dump	0.74
R 8- Landfill	0.69
R 9-Underground artificial debris	0.69
R10- Groundwater infiltration	0.76
R11- Soft compressible soil	0.74
R12- Groundwater/water table	0.66
R13- Soft clays, organic silts, or peat	0.73
R14- Highly compressive soils	0.77

Table 4.5 shows factors and groups of risk factors, respondent's scorings (from 1=very low important to 5=very high important), computed RII's, and ranks. The factors rank results shown in figure 4.2.

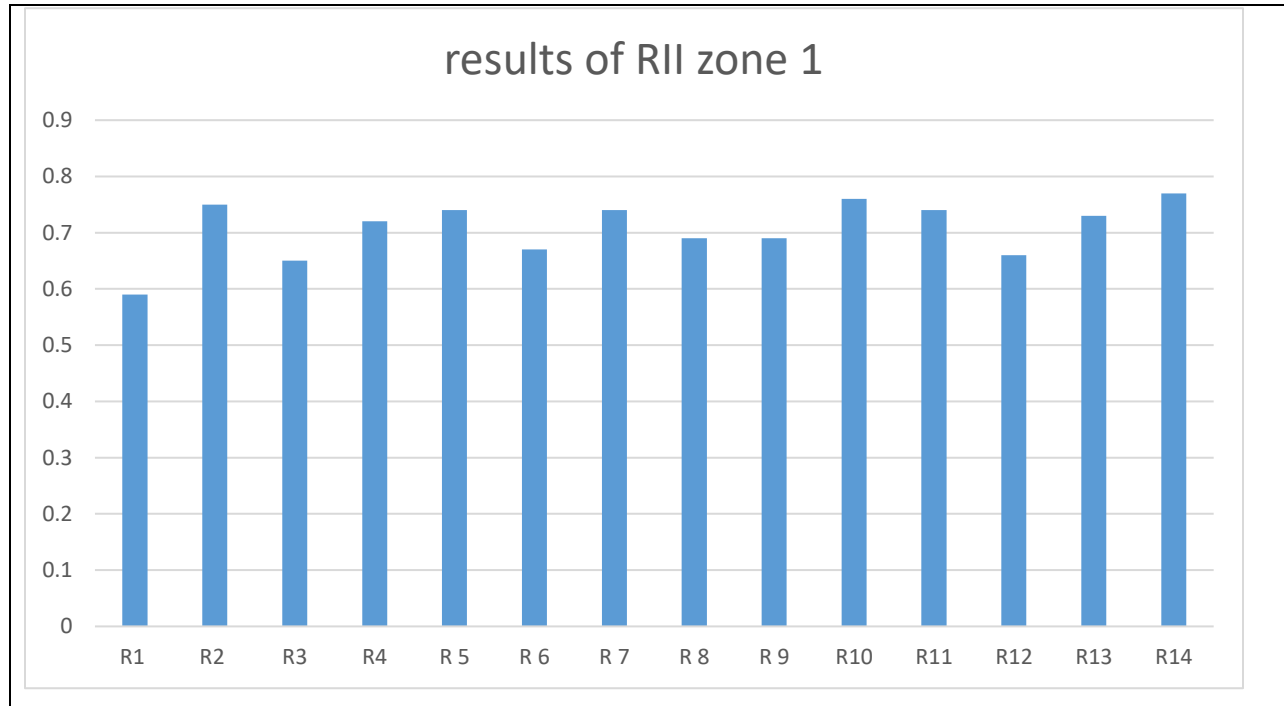


Figure 4.2: The RII Ranks of Geotechnical Risk Factors in Zone 1

It can be seen that the R14-Highly compressive soils rank came out on top (77 percent). The most major component that caused risk difficulties was the highly compressed soil of geotechnical factors. Soil shrinks in volume when it is exposed to a mechanical stress. As a result of an external load, soil density (densification) is reduced (compression). This risk implies that the amount of compaction energy used, such as weight, vibration, and number of passes, is associated with nature and the kind of soil compacted, such as sand or clay, grading, and plasticity. R2- Sensitivity of public consideration is the next risk factor (75 percent). The nature of the inhabitants in this area poses a significant obstacle to infrastructure initiatives.

4.2.2. RII Results of Zone 2

In this section, the results of relative importance index, RII, was computed for each factor to identify the risk factors in geotechnical infrastructure projects in zone 2. According to the computed RII values, these factors were ranked.

Table 4.6: RII of Risk Factors Respond Scoring in Zone 2

factor	RII
R1 - Settlement of adjacent structure	0.67
R2- Sensitiveness of public consideration	0.67
R3- There are buried traces	0.65
R4 - The presence of cemeteries as a result of wars	0.68
R 5-Existing structures likely to be impacted by the work	0.78
R 6-Existing Contaminated material	0.74
R 7- construction waste dump	0.69
R 8- Landfill	0.69
R 9-Underground artificial debris	0.65
R10- Groundwater infiltration	0.71
R11- Soft compressible soil	0.69
R12- Groundwater/water table	0.72
R13- Soft clays, organic silts, or peat	0.71
R14- Highly compressive soils	0.74

It can be shown that existing structures are more likely to be impacted by the task rank presented (78 percent). In densely populated areas, it is common to need extensive excavations or use massive vibrating gear close to existing buildings. Planning and engineering must be rigorous to prevent nearby structures or infrastructure harm.

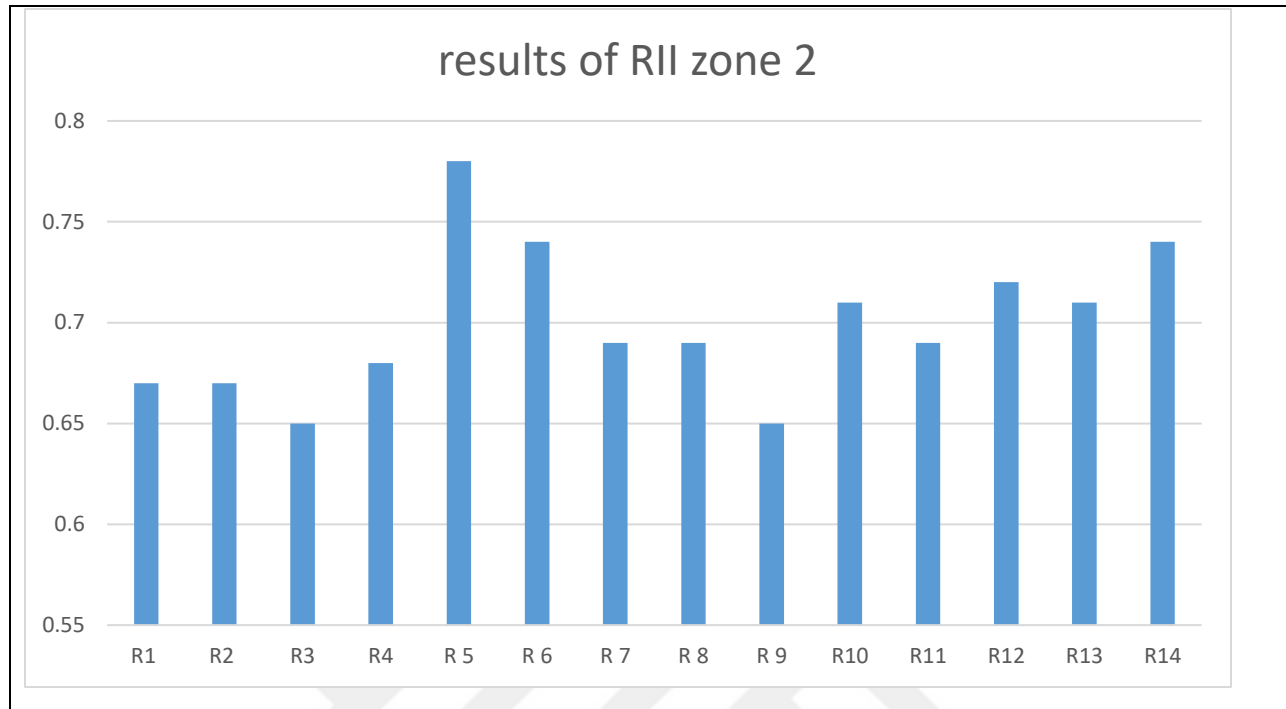


Figure 4.3: The RII Ranks of Geotechnical Risk Factors in Zone 2

To eliminate this risk effect, utilize precautionary measures to protect against deterioration and provide specific design guidelines. The information in these instructions is best practice and might be applied to other constructions in harsh situations.

4.2.3 RII Results of Zone 3

The results of the third zone relative importance index, RII, were computed in this section in order to detect risk concerns in geotechnical infrastructure projects. These factors were ordered based on the derived RII values. It can be seen that extremely compressive soils have a higher ranking (78 percent). This conclusion indicates that in the soil nature, zone 1 and zone 3 have a link.

Table 4.7: RII of Risk Factors Respond Scoring in Zone 3

factor	RII
R1 - Settlement of adjacent structure	0.74
R2- Sensitiveness of public consideration	0.75
R3- There are buried traces	0.65
R4 - The presence of cemeteries as a result of wars	0.71
R 5-Existing structures likely to be impacted by the work	0.65
R 6-Existing Contaminated material	0.7
R 7- construction waste dump	0.72
R 8- Landfill	0.75
R 9-Underground artificial debris	0.71
R10- Groundwater infiltration	0.77
R11- Soft compressible soil	0.74
R12- Groundwater/water table	0.63
R13- Soft clays, organic silts, or peat	0.65
R14- Highly compressive soils	0.78

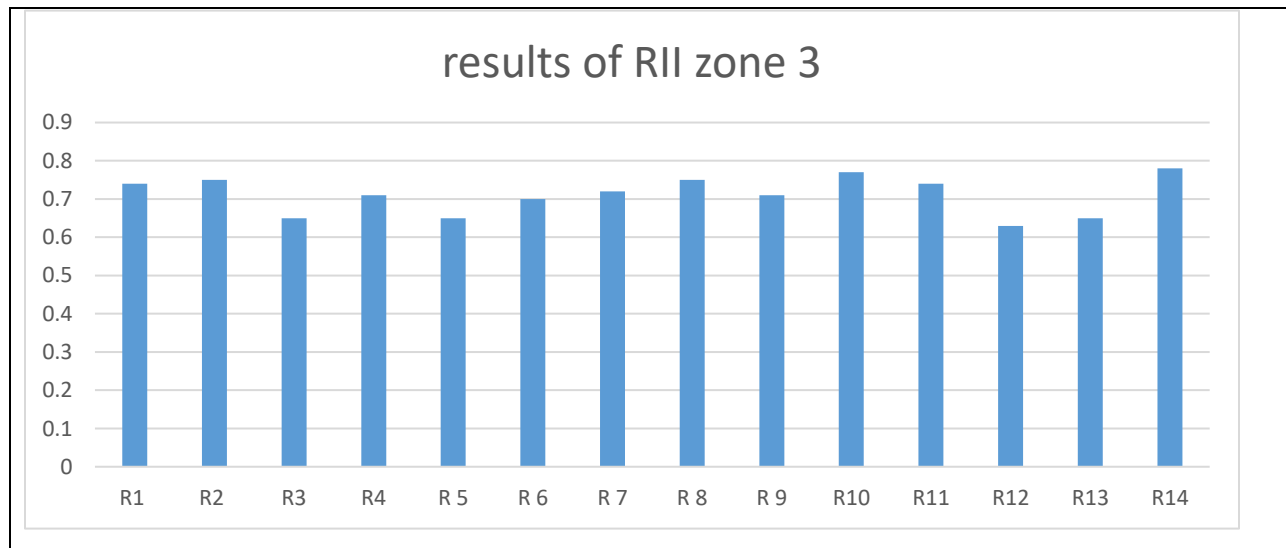


Figure 4.4: The RII Ranks of Geotechnical Risk Factors in Zone 3

4.3 MATLAB MODEL

After all of the data has been collected, the following step is to rank the risks using the AHP approach. The ability of AHP to check and reduce the inconsistency of expert opinions is its main benefit. The purpose of AHP is to develop a matrix that performs effectively on data in order to get the best risk factor weights. Using the geometric mean of individual evaluations, this strategy allows for group decision-making by consensus. AHP is a multi-objective algorithm that generates scales of values from pairwise comparisons and ratings. The situations were created in two stages. The initial step is to identify effective value differences that can provide useful information for ranking risk variables. Many questionnaires and interviews with Iraqi managers and engineers were conducted to get to this point. The researcher then put the AHP algorithm to the test in order to determine the impact of geotechnical risks on infrastructure projects. The key issue with this project is figuring out how to cope with such massive amounts of data. The researcher organizes and classifies the data in order to provide a good depiction of the current methods. AHP is used in decision-making settings involving risk groups, where a group of decision-makers examines the expert's responses to questionnaires using pair-wise comparisons (comparing items to one another two at a time). The decision-makers employ their judgements about the relative value of the elements in the comparison process. The AHP technique is used to solve problems by first identifying the problem and establishing the type of knowledge necessary. The decision hierarchy is thus structured with the aim at the top, followed by the objectives from a broad perspective, intermediate levels (criteria on which subsequent elements are based), and finally the lowest level (typically a set of choices). The weighting of the priorities in the level below is based on the priorities acquired from the comparisons. Every piece is given the same priority weighting. To arrive at the overall or global priority, the weighted values of each element in the level below are added together. Continue this process of analyzing and adding alternatives until the final priorities of the lowest level options have been decided. The proposed AHP framework was shown using data from a real-life questionnaire. The infrastructure geotechnical risk factors endangering the project's safety and performance are listed in a risk-based hierarchy. Based on the soil specifications of the region, a hierarchy of three zones was created. The matrices were created to assist the expert in performing pairwise comparisons between the hierarchy's elements. The MATLAB code will observe the preference score of weighted product model as shown in figure 4.5.

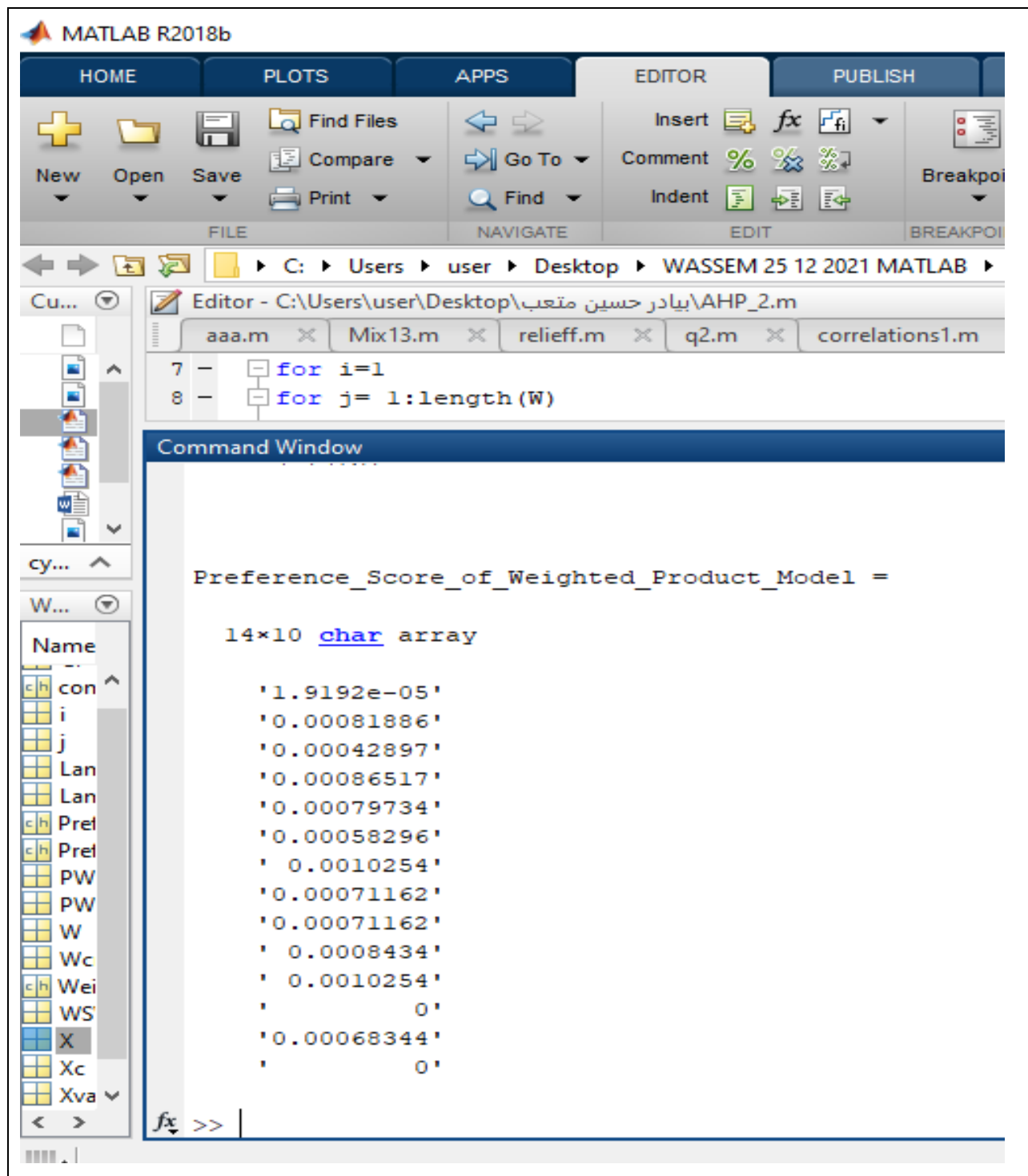


Figure 4.5: The MATLAB Code Results Observation

4.4 AHP RESULTS

The findings of the AHP analysis are presented in the following sections. The results of the AHP analysis are shown in the tables in the following sections for each zone. The selected 14 hazards were highlighted as having high important levels in the risk assessment of infrastructure projects based on geotechnical consequences based on these ranking results.

4.4.1 Zone 1 AHP Outcomes

To identify risk factors in geotechnical infrastructure projects, the AHP was calculated for each factor. These criteria were ordered based on the AHP values obtained. .

Table 4.8: AHP of Risk Factors Respond Scoring in Zone 1

Factor	AHP results
R1 - Settlement of adjacent structure	'5.8569e-05'
R2- Sensitiveness of public consideration	' 0.002499'
R3- There are buried traces	' 0.0013091'
R4 - The presence of cemeteries as a result of wars	' 0.0026403'
R 5-Existing structures likely to be impacted by the work	' 0.0024333'
R 6-Existing Contaminated material	' 0.001779'
R 7- construction waste dump	' 0.0031292'
R 8- Landfill	' 0.0021717'
R 9-Underground artificial debris	' 0.0021717'
R10- Groundwater infiltration	' 0.0025738'
R11- Soft compressible soil	' 0.0031292'
R12- Groundwater/water table	'0.00080433'
R13- Soft clays, organic silts, or peat	' 0.0020857'
R14- Highly compressive soils	' 0.002254'

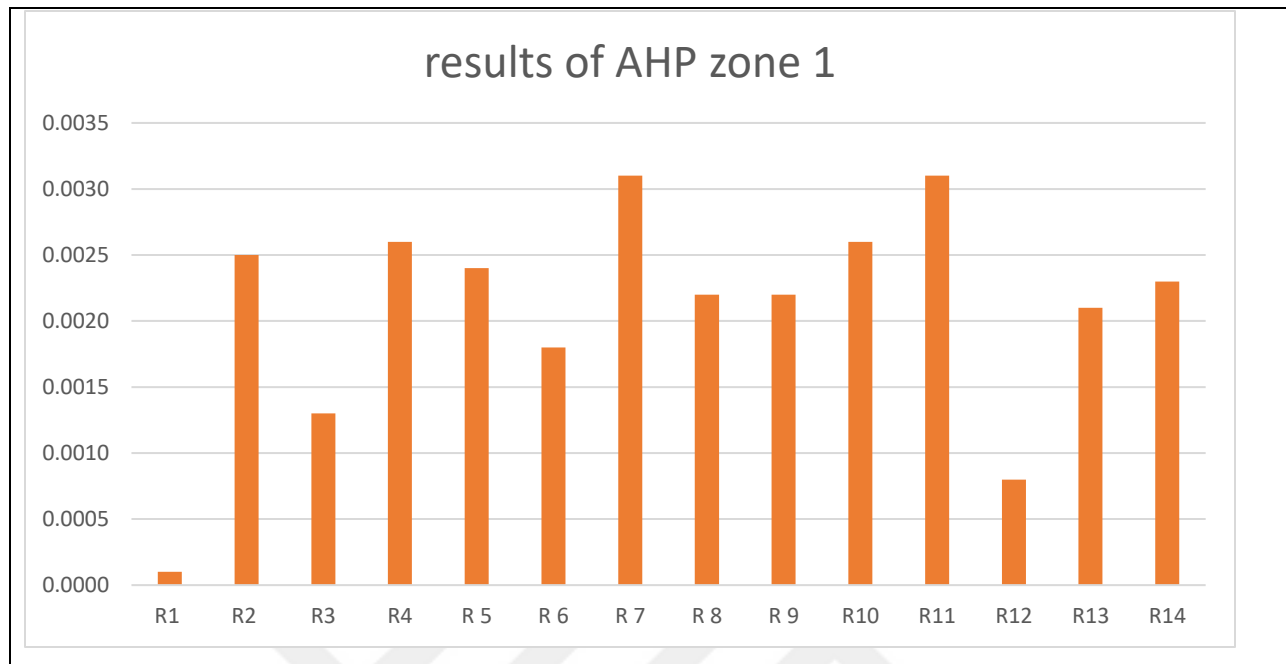


Figure 4.6: The AHP Ranks of Geotechnical Risk Factors in Zone 1

The R7-construction waste dump and R11-soft compressible soil rank were both (0.0031292), indicating that the R7-construction waste dump had the higher rank. A soft compressive soil is one that has a low shear strength, is extremely compressible, and has a low permeability. It carries a considerable geotechnical risk. In addition, the parent construction waste dump as a significant element in geotechnical concerns

Table 4.9: Comparison between RII and AHP Ranks

factor	AHP rank	RII rank
R2- Sensitiveness of public consideration	4	3
R4 - The presence of cemeteries as a result of wars	2	
R 5-Existing structures likely to be impacted by the work	5	4
R 7- construction waste dump	1	4
R10- Groundwater infiltration	3	2
R11- Soft compressible soil	1	4
R13- Soft clays, organic silts, or peat		5
R14- Highly compressive soils		1

These elements were shown to be an interesting factor in geotechnical risk factors, according to the findings. When we compare the RII and AHP findings, we can see that the top five higher ranks, as indicated in table 4.9, are significantly higher. According to the experts, the results show that adopting the AHP approach has a higher level of reliability. The reason for this was the significant construction waste in this area, which also contains many cemeteries, particularly in the Najaf region; however, it is evident from the table that the RII technique did not examine this point of view.

4.4.2 AHP Results of Zone 2

The AHP, was computed based on the second zone questionnaire frequency results for each factor to identify the risk factors in geotechnical infrastructure projects. According to the computed AHP values, these factors were ranked as in table 4.10.

Table 4.10: AHP of Risk Factors Respond Scoring in Zone 2

factor	AHP
R1 - Settlement of adjacent structure	' 0.014207'
R2- Sensitiveness of public consideration	' 0.014207'
R3- There are buried traces	' 0.010573'
R4 - The presence of cemeteries as a result of wars	' 0.01815'
R 5-Existing structures likely to be impacted by the work	' 0.036'
R 6-Existing Contaminated material	' 0.02499'
R 7- construction waste dump	' 0.01927'
R 8- Landfill	' 0.017343'
R 9-Underground artificial debris	'0.0079915'
R10- Groundwater infiltration	' 0.014057'
R11- Soft compressible soil	' 0.01927'
R12- Groundwater/water table	' 0.006246'
R13- Soft clays, organic silts, or peat	' 0.020229'
R14- Highly compressive soils	' 0.019432'

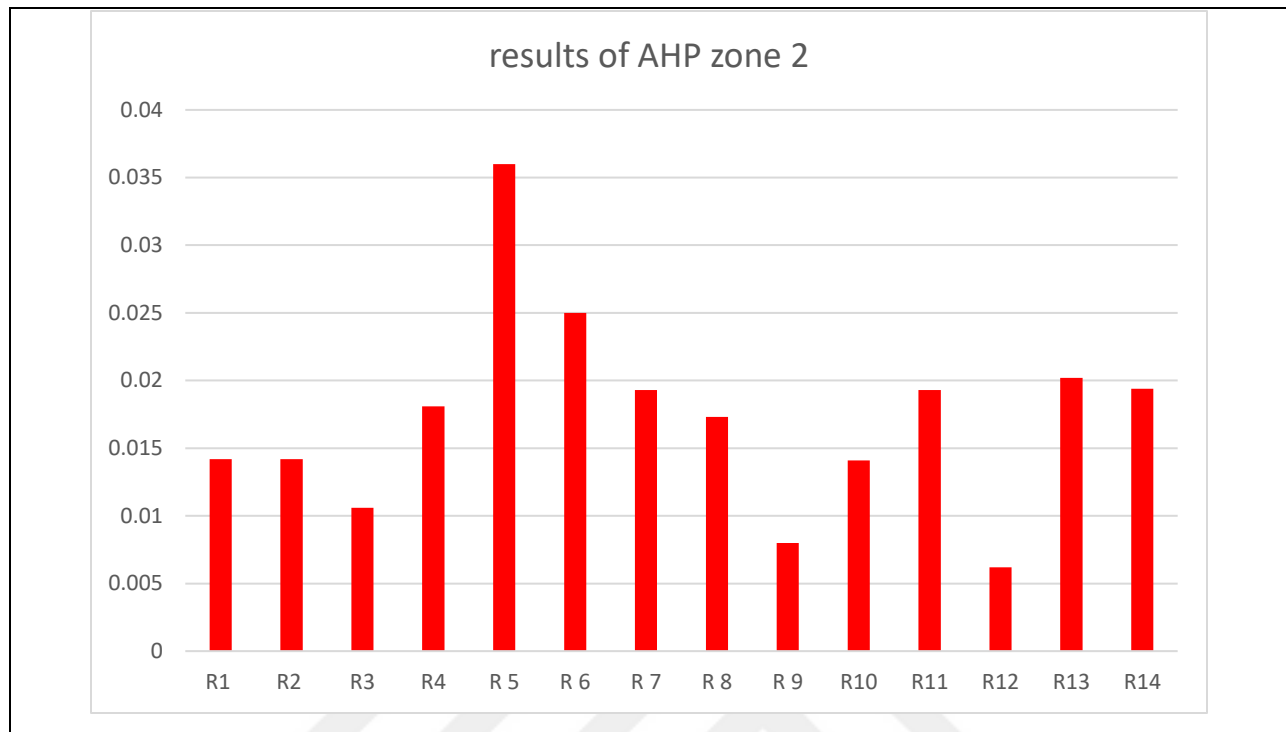


Figure 4.6: The AHP Ranks of Geotechnical Risk Factors in Zone 2

The results observed an agreement between RII and AHP results due to the similarity in R5 factor results which represent the high possibility to damage the exist building structure in this region.

4.4.3 AHP Results of zone 3

The risk indicators identified through AHP analysis are of critical importance in assessing the risk of infrastructure projects based on geotechnical consequences. The AHP was calculated in zone 3 using the frequency findings from the questionnaire for each element to identify risk factors in geotechnical infrastructure projects. These criteria were ordered based on the AHP values obtained. The results show that the AHP approach has a high level of reliability. The reason for this was R13's high ranking, which represents a significant challenge in the Basra region.

Table 4.11: AHP of Risk Factors Respond Scoring in Zone 3

factor	AHP
R1 - Settlement of adjacent structure	' 0.0020008'
R2- Sensitiveness of public consideration	' 0.0021309'
R3- There are buried traces	' 0.0011163'
R4 - The presence of cemeteries as a result of wars	' 0.0021859'
R 5-Existing structures likely to be impacted by the work	' 0.0011163'
R 6-Existing Contaminated material	'0.00022231'
R 7- construction waste dump	' 0.0022515'
R 8- Landfill	'0.00075852'
R 9-Underground artificial debris	' 0.0020094'
R10- Groundwater infiltration	' 0.00162'
R11- Soft compressible soil	' 0.0026684'
R12- Groundwater/water table	'0.00035117'
R13- Soft clays, organic silts, or peat	' 0.0011163'
R14- Highly compressive soils	' 0.0020227'

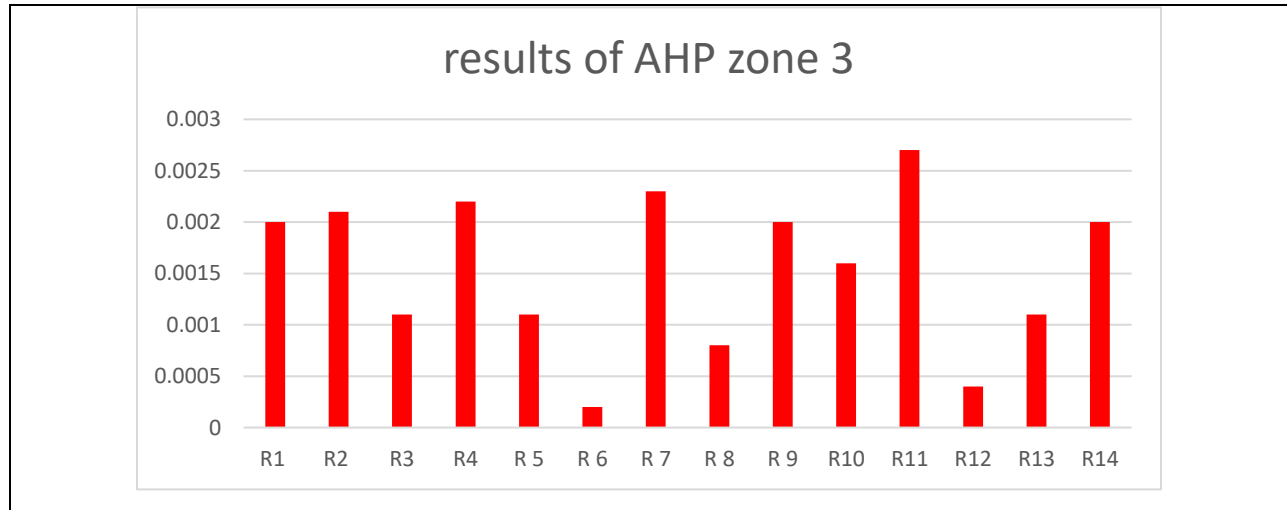


Figure 4.7: The AHP Ranks of Geotechnical Risk Factors in Zone 3

4.5 RISK EVALUATION UNDER DIFFERENT PROJECT CONDITIONS

The geotechnical risks in the infrastructure projects goes through two main phases, the first phase is the skeleton and the finishing phase. Table 4.12 presents the influential infrastructure causes which are the project size and depth inside the earth.

Table 4.12: The Impact of Variables on Infrastructure Projects

	Influence factors on infrastructure project
Case 1	underground depth of the project
Case 2	size of project

The risk results based on these influence factors are:

Table 4.13: The Impact of Risk Factors on Infrastructure Projects Based on Case 1

case 1	RII related to high depth	RII related to low depth
R12- Groundwater/water table	0.84	0.66
R14- Highly compressive soils	0.87	0.77

Table 4.14: The Impact of Risk Factors on Infrastructure Projects Based on Case 2

case 2	RII related to big size	RII related to small size
R1 - Settlement of adjacent structure	0.84	0.59
R2- Sensitiveness of public consideration	0.87	0.75
R3- There are buried traces	0.87	0.65
R4 - The presence of cemeteries as a result of wars	0.83	0.72

When the work in the infrastructure is exposed to different influences, the impact of the risks on the project changes. It may get stronger or weaker depending on the type of risk and the nature of the project. For the purpose of verifying the system that was implemented in this thesis, the researcher introduced different factors for the purpose of knowing the risk response. The results show the success of the system response, as shown in the figures below.

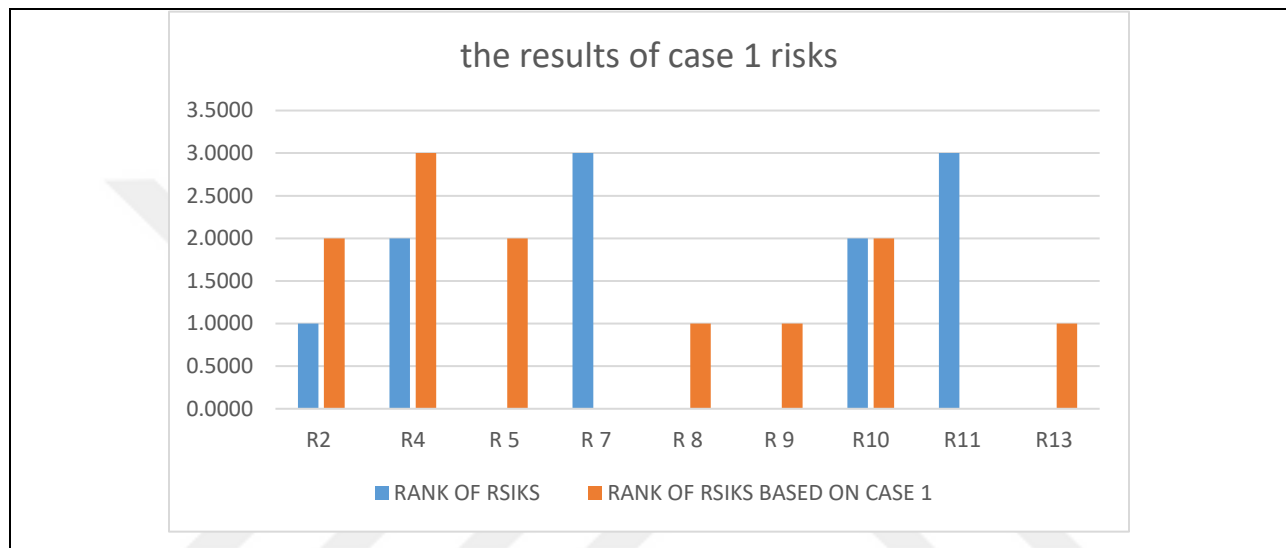


Figure 4.8: The AHP Ranks of Geotechnical Risk Factors Case 1

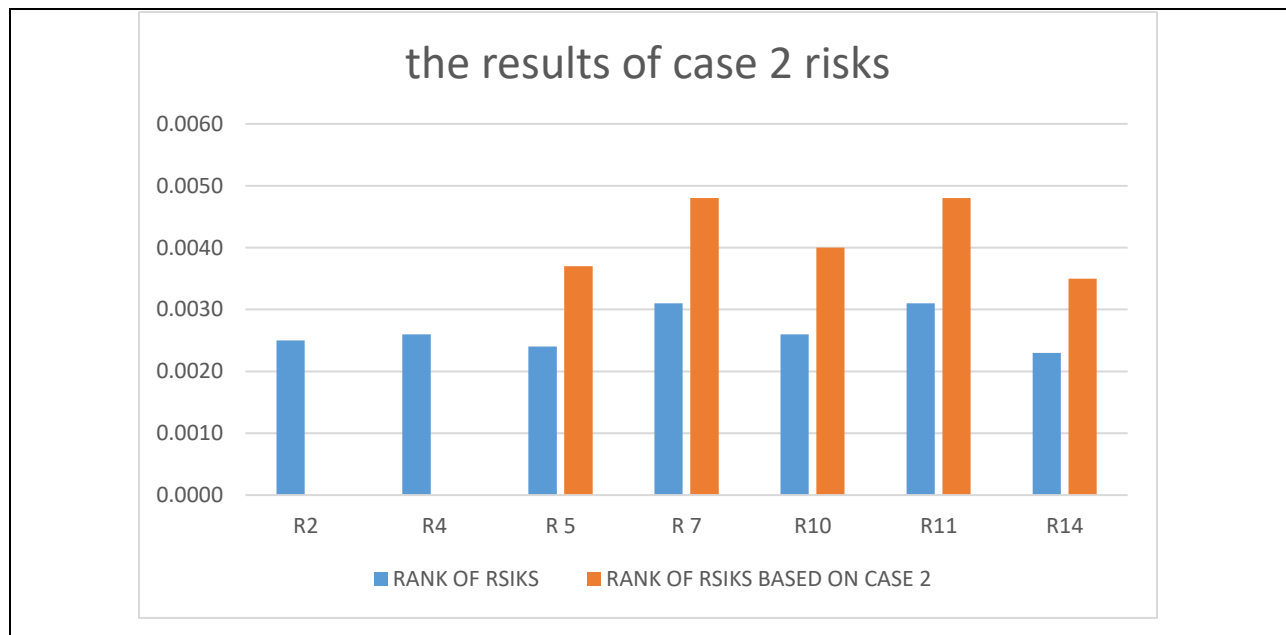


Figure 4.9: The AHP Ranks of Geotechnical Risk Factors Case 2

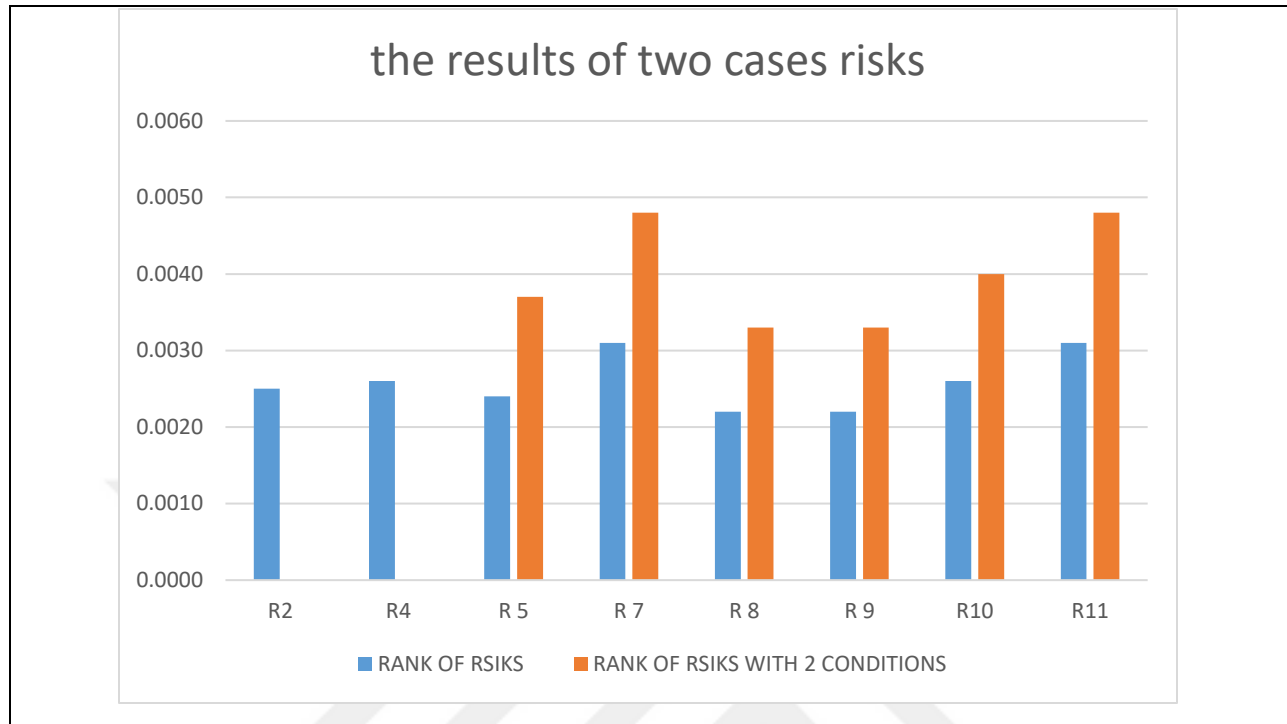


Figure 4.10: The AHP Ranks of Geotechnical Risk Factors in Two Cases

5. CONCLUSION AND RECOMMENDATION

The aim of this research is to provide a new approach for estimating the project risks arising from the geotechnical in southern Iraq by creating a model that may help the parties involved in infrastructure projects in obtaining the obstacles and risks in the early stages of the project. To achieve this goal, the following procedures and processes were followed:

- a) Effective risk elements and the degree of their impact were determined through the two questionnaires and the opinions of experts in infrastructure projects through interviews with experts and exploratory research of previous studies. 14 types of risks affecting infrastructure projects were selected.
- b) Creating an AHP model involved a number of operations, the first of which was choosing the application that would be used to build the model. In addition to the simplicity of its use and the ability to draw conclusions, the Microsoft Excel application for basic risk assessment and the MATLAB program were chosen to calculate the degree of impact of each type of risk.
- c) The system was tested by dividing the southern region in Iraq into three main divisions according to the type of soil geology, history and degree of urbanization in each region. The flexibility of the system was tested using other factors such as project size and project drilling depth.

The results were excellent, and the risk prognosis was excellent, according to experts' opinion.

5.1 RECOMMENDATIONS

The latest study showed promising results in identifying risks, and this technology will continue to make significant progress, particularly in the field of infrastructure engineering. However, some recommendations should be made to decision makers in the project implementation sector, in addition to future studies, to support the results of this study:

- a) All parties implementing infrastructure projects should be more aware of geotechnical risks and pay more attention to the use of this information.
- b) It is suggested that there should be extensive studies of the hazards and that standardized studies divided on the basis of the geological classification of the hazards be organized

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