

**ASSESSMENT OF WATER RESOURCES
VULNERABILITY USING GEOGRAPHIC
INFORMATION SYSTEMS (GIS) AND
ANALYTIC HIERARCHY PROCESS
(AHP) IN AL-KARAK, JORDAN**

FAYZA ABDALKREEM A ALSHAMAEN

UNIVERSITI SAINS MALAYSIA

2025

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by

FAYZA ABDALKREEM A ALSHAMAEN

**Thesis submitted in fulfillment of the requirements
for the degree of
Doctor of Philosophy**

March 2025

ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude to my university for providing me with the resources and support to complete my thesis. Without their guidance and encouragement, I would not have been able to reach this milestone.

I am also incredibly grateful to my supervisor Dr. Wan Mohd Muhiyuddin Wan Ibrahim for his invaluable advice, constructive feedback, and unwavering support throughout the research process. His mentorship has been instrumental in shaping my work and helping me grow as a scholar.

To my husband and children, words cannot express how grateful I am for your unwavering love, understanding, and patience during this challenging journey. Your constant support, encouragement, and sacrifices have been the driving force behind my success.

Thank you for believing in me and standing by my side every step of the way. This thesis is as much a testament to your unwavering support as it is to my hard work. I am forever grateful for all that you have done for me.

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LIST OF ABBRIVIATIONS

AHP	Analytic Hierarchy Process
CR	Consistency Ratio
DoS	Department of Statistics
DS	Dead Sea
IPCC	Intergovernmental Panel on Climate Change
GIS	Geographic Information System
MD	Metrological Department
MOA	Ministry of Agriculture
MWI	Ministry of Water and Irrigation
RS	Remote Sensing
SPSS	Statistical Package for the Social Sciences
WAJ	Water Authority of Jordan
MCDA	Multi-Criteria Decision Analysis
GPZs	Groundwater Potential Zones

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**PENILAIAN TERHADAP KERENTANAN SUMBER AIR MENGGUNAKAN
SISTEM MAKLUMAT GEOGRAFI (GIS) DAN PROSES HIERARKI
ANALITIK (AHP) DI AL-KARAK, JORDAN**

ABSTRAK

Perubahan iklim dan pertumbuhan populasi global telah memburukkan lagi kekurangan air, menonjolkan keperluan mendesak untuk penilaian kelemahan menyeluruh dalam sektor air. Walaupun penyelidikan meluas telah menangani kesan perubahan iklim terhadap sumber air, jurang kritikal kekal dalam membangunkan rangka kerja yang komprehensif dengan penunjuk yang mencukupi disesuaikan khusus untuk kelemahan sumber air. Jordan, yang disenaraikan sebagai salah satu negara paling miskin air di dunia, menghadapi cabaran yang lebih teruk disebabkan iklimnya yang gersang dan tekanan yang semakin meningkat terhadap sumber daripada kemasukan pelarian. Dengan unjuran yang menunjukkan penurunan bahagian air per kapita tahunan negara daripada 145 m³ dalam tahun optimum kepada kurang daripada 90 m³ menjelang 2025, krisis ini menekankan keperluan untuk pengurusan air yang mampan untuk memastikan pembangunan dan daya tahan jangka panjang. Kajian ini memfokuskan pada penilaian kelemahan sumber air di Al-Karak, Jordan, dalam tempoh 36 tahun (1987–2020). Dengan menyepadukan Penderiaan Jauh (RS), Sistem Maklumat Geografi (GIS), dan Proses Hierarki Analitikal (AHP), model berasaskan GIS telah dibangunkan untuk menilai kesan jangka panjang perubahan iklim dan mengenal pasti kawasan yang paling terdedah kepada kekurangan air di kawasan separa gersang ini. Penyelidikan mengenal pasti pembolehubah spatial utama yang mempengaruhi kerentanan air, termasuk kerpasan, suhu, jenis tanah, tutupan tanah, kepadatan penduduk, permintaan air, cas semula air bawah tanah, topografi dan

kualiti air bawah tanah. Faktor-faktor ini berinteraksi dengan cara yang kompleks, mempengaruhi ketersediaan dan kualiti air, dan menyediakan data penting untuk membangunkan strategi pengurusan air yang disasarkan. Hasil utama kajian ini ialah pembangunan indeks kerentanan sumber air yang disesuaikan untuk kawasan separa gersang. Indeks ini menawarkan alat praktikal untuk mengukur dan menilai kelemahan air di kawasan seperti Al-Karak, membolehkan membuat keputusan yang lebih baik dalam pengurusan sumber air. Pengesahan peta Indeks Kerentanan Sumber Air (WRVI) dicapai melalui proses pelbagai langkah, menggabungkan kualiti air dan data piezometrik daripada 22 stesen pemantauan selama beberapa dekad. Analisis perbandingan mendedahkan penurunan ketara dalam paras air bawah tanah, dengan penurunan sehingga 10 meter sepanjang tempoh kajian. Penemuan ini sejajar rapat dengan zon kelemahan yang dikenal pasti dalam peta WRVI, mengesahkan ketepatan dan kaitan indeks dalam mewakili kelemahan air bawah tanah yang sebenar. Selain itu, analisis korelasi menggunakan matriks kekeliruan menghasilkan indeks Kappa 0.6552, menunjukkan persetujuan yang besar antara klasifikasi kelemahan dan data kualiti air. Keputusan kajian menunjukkan nilai kelemahan antara 0.44 hingga 0.5, menggambarkan keberkesanan RS bersepadu, GIS, dan metodologi AHP dalam menyediakan pandangan yang boleh diambil tindakan untuk pengurusan sumber air yang mampan. Pendekatan ini amat berharga bagi wilayah yang ingin mengimbangi kekurangan air dengan matlamat pembangunan, menawarkan laluan praktikal untuk meningkatkan daya tahan di kawasan kekurangan air.

**ASSESSMENT OF WATER RESOURCES VULNERABILITY USING
GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND ANALYTIC
HIERARCHY PROCESS (AHP) IN AL-KARAK, JORDAN**

ABSTRACT

Climate change and global population growth have exacerbated water scarcity, highlighting the urgent need for comprehensive vulnerability assessments in the water sector. While extensive research has addressed the impacts of climate change on water resources, a critical gap remains in developing a comprehensive framework with sufficient indicators tailored specifically for water resource vulnerability. Jordan, ranked as one of the world's most water-poor countries, faces compounded challenges due to its arid climate and the growing pressure on resources from an influx of refugees. With projections indicating a decline in the country's annual per capita water share from 145 m³ in optimal years to less than 90 m³ by 2025, this crisis underscores the need for sustainable water management to ensure long-term development and resilience. This study focuses on assessing water resource vulnerability in Al-Karak, Jordan, over a 36-year period (1987–2020). By integrating Remote Sensing (RS), Geographic Information Systems (GIS), and the Analytical Hierarchy Process (AHP), a GIS-based model was developed to evaluate the long-term impacts of climate change and identify areas most vulnerable to water scarcity in this semi-arid region. The research identified key spatial variables influencing water vulnerability, including precipitation, temperature, soil type, land cover, population density, water demand, groundwater recharge, topography, and groundwater quality. These factors interact in complex ways, influencing both water availability and quality, and provide crucial data for developing targeted water management strategies. A central outcome of this study

is the development of a water resource vulnerability index tailored for semi-arid regions. This index offers a practical tool to quantify and assess water vulnerabilities in areas like Al-Karak, enabling better decision-making in water resource management. The validation of the Water Resource Vulnerability Index (WRVI) map was achieved through a multi-step process, incorporating water quality and piezometric data from 22 monitoring stations over several decades. The comparative analysis revealed significant declines in groundwater levels, with decreases of up to 10 meters over the study period. These findings closely align with the vulnerability zones identified in the WRVI map, confirming the accuracy and relevance of the index in representing actual groundwater vulnerabilities. Additionally, a correlation analysis using a confusion matrix produced a Kappa index of 0.6552, indicating substantial agreement between the vulnerability classifications and water quality data. The study's results demonstrate vulnerability values ranging from 0.44 to 0.5, illustrating the effectiveness of the integrated RS, GIS, and AHP methodologies in providing actionable insights for sustainable water resource management. This approach is particularly valuable for regions seeking to balance water scarcity with development goals, offering a practical pathway to enhance resilience in water-scarce areas.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Water is a valuable resource for humans and a variety of sectors, including agriculture, industry, and home use (Nepal et al., 2021; Tzanakakis et al., 2020). It helps to maintain ecosystems, but it also creates calamities for human societies, such as floods and droughts (Mishra, 2023); Brown et al., 2015). all over the world. Total freshwater withdrawals worldwide reached 4 trillion m³ in 2014, reflecting a six-fold increase from 1900 to 2014 Bischoff-Mattson et al., 2020; Alcamo et al., 2003; Flörke et al., 2013). Water usage per capita varies considerably throughout the world, depending on latitude, temperature, and the level of development of nations or areas. According to the Intergovernmental Panel on Climate Change (IPCC) (2014), greenhouse gas emissions will have a direct influence on the global hydrological cycle, affecting water supply and demand (Gain et al., 2012).

The severe scarcity of water poses a significant challenge to Jordan's economic and developmental progress (Jordan's 3rd National Communications, 2014). Population growth, migration from neighboring countries, shared water problems, and the impact of climate change have exacerbated the situation, leading to limited water resources. Currently, the average rainfall in Jordan ranges from 50 to 570 mm annually (AL-Areeq, 2021), with a long-term rain rate estimated at 8 billion cubic meters. Unfortunately, less than 10% of this rate is usable for surface drainage and groundwater recharge (less than 800m³). Consequently, Jordan's per capita share of water is one of the lowest globally, less than 100m³ per person per year, and it

continues to decline due to population growth and forced migration from neighboring countries (Minister of Water and Irrigation, 2016).

These factors have adverse effects on Jordan's water sector, leading to increased demand for water against limited resources. As a result, numerous water resources have been depleted, and the groundwater level has sharply declined (Al Karablieh and Salman, 2016). This depletion has also led to a decline in water quality (Qtaishat, 2020). Furthermore, the impact of climate change has worsened the water crisis, with the region experiencing a temperature increase of more than 0.2 degrees Celsius per decade. Over the past 50 years, Amman's average annual temperatures have risen by over 1.5 degrees Celsius, while rainfall has decreased by more than 50 mm annually. This has resulted in an increase in severe heatwaves and more days with high temperatures (Alwadi and Abdulla, 2022).

Climate change is projected to have both global and local effects on the earth's surface. One of these outcomes will be a decrease in freshwater supplies and an increase in water demand (Jibrin and Suleiman, 2022). Water resource management has already become a major concern. Physically based climate models are used to make future climate forecasts. Evaporation will rise in the future due to warming climatic conditions, according to these global and regional climate models (Kim et al., 2021). It is expected that evaporation will increase in several parts of the world (Soares and Lima, 2022). Evaporation will increase the number of hot days and heat waves (Lague et al., 2023).

The assessment of "vulnerability" varies according to the definition given to this term, because the term can carry different interpretations in different disciplines and areas of expertise. Vulnerability research has developed, and this study will focus

on the vulnerability of water resources to the effects of climate change. The assessment of vulnerability must include various aspects of the primary and secondary impacts of climate change on water resources so that a framework for the concept of vulnerability is developed in this context (Gumel, 2022). These systems are assessed for their vulnerability to stress, their sensitivity to hazards, and their ability to resist, respond to, benefit from, recover from, and adapt to impacts. This possibility only appears when the system is exposed to the effect of the stress factor, so vulnerability becomes a latent component that can only be observed when a climatic phenomenon occurs (Trenberth, 2020). Water is of paramount importance for development, and its significance is underscored by its inclusion as one of the United Nations' Sustainable Development Goals (SDGs; Mujtaba et al., 2024), specifically SDG 6: Safe drinking water and sanitation. Addressing water-related challenges, such as ensuring clean water supply and protecting against water hazards, is essential for progress in achieving several other SDGs. Notably, it supports food security (SDG2: Zero hunger) and the preservation of life on land (SDG15).

Efficient water management also plays a critical role in accomplishing various other sustainable development goals, including those directly related to agriculture (Goal 2) and energy production (Goal 7), as well as those addressing hydrological risks (Goal 6 and 13) and poverty reduction (Goal 1) (Chirambo, 2023). The interconnected nature of these goals emphasizes the significance of water resources in promoting overall sustainable development and improving the well-being of communities worldwide.

1.2 Issues and Problem Statements

The study of Vulnerability Assessment of Water Resources to Climate Change Using GIS and RS. Focuses on three key challenges contributing to water scarcity in Jordan. These challenges include the increased demand and population growth, climate change impacts on water resources, and the decline in groundwater levels due to over-extraction. By examining these issues, the study aims to provide valuable insights for developing effective water management strategies and enhancing the resilience of Jordan's water systems to cope with the effects of climate change.

1.2.1 Water Scarcity in Jordan due to the increase in population (high demand for water)

Jordan's rapid population increase has compounded the country's already severe water constraint challenges. The growing population puts an enormous strain on the limited water resources, exacerbating pre-existing difficulties. As the population grows, so does the demand for water for home, agricultural, and industrial uses, resulting in unsustainable water consumption patterns and increased strain on the existing water supply (Ministry of Water and Irrigation, 2016).

The surge in demand for water services in Jordan can be attributed to various factors, including population growth, urbanization, improved access to services, and the influx of refugees from neighboring conflict zones (Al-Addous et al., 2023). Jordan's population reached nearly 11 million in 2021, with over 90% residing in urban areas, a stark contrast to the 3.5 million people and 75% urbanization rate in 1990 (Almulhim and Cobbinah, 2023; United Nations, 2019). Moreover, Jordan hosts one of the highest proportions of refugees globally, with 89 refugees per 1,000 inhabitants as of 2021 (Al-Baz, 2021).

The escalating demand for water has overwhelmed the country's water supply network, leading to rationing practices over the years. Alarming, Jordan's water reserves are now only sufficient to support a population of 3 million, as the per capita freshwater availability has declined tenfold since the 1960s. It is projected to decrease by 50% by the end of the century (Yoon et al., 2021). A study by Yoon et al. indicates an annual increase in water stress in Jordan of 1%-1.5%, suggesting that these trends will persist into the future.

Jordan's population growth has been further accelerated by the influx of refugees. Between 2010 and 2020, the population grew from 7.2 million to over 10.8 million, a period during which 1.1 million Syrian refugees fled the Syrian Civil War to Jordan (Yoon et al., 2021). In response to the water crisis, Jordan has made strides in improving water supply efficiency. In Amman, over 95% of wastewater is treated and recycled. However, the country's water distribution system remains inefficient, with 50% of piped water lost as nonrevenue water (NRW) due to leaks, theft, incorrect meter readings, or underbilling (Al-Baz, 2021).

Households in Amman receive piped water for an average of 36 hours per week, with some lower-income neighborhoods receiving as little as 24 hours, while wealthier areas enjoy up to five days of continuous water supply (Almulhim and Cobbinah, 2023). As a result, many urban residents resort to purchasing water from tanker trucks, which obtain water from private agricultural wells through formal and informal markets. Ecologically, both groundwater and surface-water extraction by Jordan and upstream riparian nations have caused severe environmental damage. Notable examples include the drying of the Azraq Oasis, a designated Ramsar wetland, and the shrinking of the Dead Sea, whose shoreline recedes by one meter per year (Yoon et al., 2021).

This combination of population growth, refugee influxes, inefficient water distribution, and ecological degradation underscores the urgency of addressing Jordan's water scarcity and highlights the profound impacts on both human populations and the environment.

1.2.2 Water Scarcity in Jordan due to climate change.

Jordan's heavy reliance on rainfall for its water supply presents a serious vulnerability, especially as climate change worsens water scarcity. The gap between water supply and demand is expected to widen drastically as climate change progresses, particularly in semi-arid regions like the study area, where water resources are already limited and predominantly sourced from groundwater. Climate change, with its potential to disrupt the hydrological cycle, has caused prolonged droughts and rising temperatures, which in turn have accelerated the depletion of groundwater in Jordan. Over-extraction for agricultural, industrial, and domestic purposes has led to falling water tables and increasing salinity in many areas (Gazal, 2021).

Climate models project a decrease in annual precipitation in Jordan, which will exacerbate water scarcity and reduce water availability across various sectors (Ministry of Water and Irrigation, Jordan, 2016). Rising temperatures, combined with shifting climate patterns, are likely to increase water demand for agriculture, domestic use, and industry, further straining Jordan's already scarce water resources (Al-Addous et al., 2023). With limited surface water sources, the country is overly dependent on groundwater, and the impacts of climate change are leading to a rapid depletion of aquifers, thereby threatening long-term water security (Abdulla et al., 2018). Additionally, climate change is expected to affect water quality by altering

hydrological patterns, raising salinity levels, and increasing the risk of pollution, which together degrade both the quantity and quality of water resources (Gazal, 2021).

The adverse impacts of climate change on Jordan's water resources also extend to the ecological environment, as reduced river flows and higher temperatures threaten freshwater ecosystems, resulting in biodiversity loss and degradation of ecosystem services (Abdulla et al., 2018). In a study by Abdulla (2020), projections show warming in Jordan of +2.5°C to +5°C by the end of the century, accompanied by a reduction in annual precipitation by 10% to 37%, reflecting significant shifts in Jordan's climate system.

Specific studies further emphasize the localized impacts of climate change on Jordan's water resources. Al Qatarnah et al. (2018) examined climate change effects on the Azraq basin using the Water Evaluation and Planning (WEAP) model, with projections of a 2°C increase in temperature, a 20% decrease in rainfall, and a 20% reduction in groundwater recharge. These estimates directly affect the balance of water resources in the area, reinforcing the urgent need for adaptive management strategies.

A comparison between the Regional Initiative for Assessing the Effects of Climate Change on Water Resources and socio-economic vulnerabilities (CORDEX-RICCAR) and WEAP model scenarios indicates that the climate change impact on Jordan's water resources may differ from global trends. The models suggest an impending water deficit in Jordan, with climate change acting as a catalyst that exacerbates existing challenges in water resource management (World Bank, 2014).

To mitigate the impacts of climate change, there is a pressing need for solutions that address water resource management holistically. Jordan must develop a model that links physical and anthropogenic factors, integrates long, medium, and short-term

considerations, and supports sustainable water management. Such a model is essential for informed decision-making and the development of strategies that will safeguard water resources for future generations.

The region's vulnerability is underscored by IPCC projections and other studies indicating a drying trend in the Eastern Mediterranean and Middle East by the end of the 21st century (IPCC, 2013). Decreasing precipitation and rising temperatures are likely to further diminish water availability in a region already affected by sparse water resources (Kunstmann et al., 2007; Krichak et al., 2010; Peleg et al., 2015; Samuels et al., 2017). This trend is evident in the Jordan River Basin and Litani River Basin, where significant reductions in rainfall, spring flow, and streamflow have been documented (Givati & Rosenfeld, 2007; Rimmer et al., 2011; Shaban, 2009). The average water availability in Lake Kinneret has decreased from 392 million cubic meters per year MCM/year in the period 1975–2010 to 319 MCM/year in the period 1993–2010 (Rimmer & Givati, 2014). These findings highlight the severe impact of climate change on water resources and underscore the urgent need for comprehensive, adaptive water management strategies in Jordan.

1.2.3 Decline in Groundwater

Groundwater is Jordan's primary water resource, supplying approximately 75% of the total drinking water and 46% of the water used for agriculture, which itself consumes 52% of the country's total water resources (1053.6 million cubic meters or MCM). In comparison, household uses account for 45% of water consumption (Ministry of Water and Irrigation [MWI], 2017). Given its critical role, effective groundwater management is urgently needed across all levels to preserve this vital resource (Al-Kharabsheh, 2020; Ministry of Environment [MOE], 2020). However,

Jordan is experiencing a sharp decline in groundwater levels, which has become a pressing issue, as evidenced by the decreasing water levels in wells and boreholes throughout the country (Al-Qadi, 2023). This depletion has forced Jordan to increase its reliance on costly desalination processes and imported water, adding significant financial strain to the economy (MWI, 2017).

Over the past 25 years, monitoring of wells across Jordan has documented significant water level declines, with average drops of around 50 meters, and in extreme cases, up to 100 meters (Hamdan and Al-Rawabdeh, 2020). Spring discharge rates have also sharply declined: over five years, the combined average spring discharge from all aquifers dropped from 249 MCM/year (1971–1975) to 136 MCM/year (2011–2015) (MWI & BGR, 2019). This over-extraction of groundwater resources has exceeded sustainable limits, with nine of Jordan's 12 major groundwater basins being over-extracted at rates ranging from 118% to 365% of their safe yields (MWI, 2017). The total annual extraction of 624 MCM/year surpasses the safe withdrawal limit of 418.5 MCM/year, creating a dangerous overdraft of 205 MCM annually, or 50% more than the sustainable threshold.

This unsustainable extraction not only depletes renewable groundwater but also exhausts non-renewable resources. Rehabilitation of some basins may be technically impossible due to the extent of over-exploitation. The Coordinated Regional Climate Downscaling Experiment (CORDEX-RICCAR, 2019) highlights the compounded impact of climate change, forecasting a loss of 78 MCM/year in groundwater production capacity by the end of the century compared to current conditions. Groundwater flow regimes have been altered, leading to rapid depletion, drying wells and springs, and rising groundwater salinity, all of which threaten the sustainability of water resources (Burdon, 1982; Dottridge & Abu Jaber, 1999;

Salameh, 2008; Ta'any et al., 2009; Margane et al., 2015; Rödiger et al., 2017; Javadi et al., 2022).

These alarming trends illustrate the urgent need for comprehensive groundwater management strategies to ensure the sustainability of Jordan's water resources, mitigate the socio-economic impacts, and address the adverse effects of climate change on the region's hydrology.

1.3 Research Gap

There is a significant gap in integrated studies assessing the vulnerability of water resources to climate change in the Al-Karak region of Jordan. Notably, issues such as water stress, water scarcity, and the region's reliance solely on groundwater, as well as its unique natural and geographical characteristics, have not been addressed in previous studies. The vulnerability of water resources in the Arabic region has been studied in limited contexts, with a marked absence of research specifically focusing on Jordan or the Al-Karak area. This research represents the first comprehensive vulnerability assessment of water resources in Al-Karak, contributing to filling this critical gap.

Several studies, including those by Koech et al. (2020), Qin et al. (2020), Al-Kalbani et al. (2014), Hung et al. (2022), and Chhetri et al. (2020) have employed GIS techniques for vulnerability assessments of water resources. However, these studies have predominantly focused on hydrological and climatic factors, overlooking socio-economic elements such as poverty rates and water demand, which are key contributors to vulnerability. Incorporating socio-economic factors is essential for achieving a more holistic understanding of vulnerability, as these factors significantly influence water availability and demand. By integrating such socio-economic

indicators, this study enhances the comprehensiveness of vulnerability assessments and provides critical insights for the development of effective adaptation strategies.

Further, studies by Al-Karablieh and Al-Shaikh (2019), Khosravi et al. (2018), and Sadeghfam et al. (2016) have primarily focused on surface water resources, leaving a notable research gap concerning groundwater vulnerability, especially regarding recharge rates, water quality, and overall sustainability. Groundwater is a vital water resource in Jordan, and this study directly addresses this gap by focusing on the vulnerability of groundwater, recognizing its importance in the region's water supply.

Another limitation of recent vulnerability assessments is the insufficient engagement of stakeholders such as local communities, water resource managers, and policymakers. Research by De Stefano et al. (2018) and O'Connor et al. (2020) exemplifies this oversight. Effective stakeholder engagement is critical for ensuring the applicability and relevance of vulnerability assessments. By integrating local knowledge and perspectives, this study addresses the gap in stakeholder involvement, ensuring that the findings are contextually grounded and more actionable.

Moreover, vulnerability assessments often lack clear recommendations for adaptation strategies. This study contributes to filling this gap by incorporating indicators of adaptation, including rainwater harvesting, wastewater treatment, and greywater reuse—strategies that have not been sufficiently explored in prior research. These adaptation measures are crucial for mitigating the impacts of water resource vulnerability and promoting sustainable water management.

The studies conducted in this area also often fail to fully incorporate the various components of vulnerability: exposure, sensitivity, and adaptive capacity into their assessments. This research adopts a more comprehensive approach, integrating these dimensions and multiple indicators to provide a more thorough evaluation of vulnerability. Such an approach enriches the overall assessment and offers more targeted insights into the vulnerability of water resources in the Al-Karak region.

Additionally, there is a pressing need for standardized methodologies in conducting vulnerability assessments using techniques like AHP, GIS, and RS. Standardization ensures consistency and comparability across studies, making it possible to draw more robust conclusions and better interpret vulnerability data. This study advocates for a more systematic approach to using these tools, contributing to the development of a standardized framework for vulnerability assessment.

Lastly, while AHP, GIS, and RS are valuable tools for assessing physical vulnerability, they often overlook the socio-economic factors that contribute significantly to overall vulnerability. This study emphasizes the importance of incorporating socio-economic dimensions into vulnerability assessments, facilitating the development of more equitable and comprehensive adaptation strategies. By addressing these gaps, this research aims to provide a more thorough, inclusive, and actionable assessment of water resource vulnerability in Al-Karak, Jordan.

1.4 Study area

Al Karak Governorate is located in the southern part of Jordan (Figure 1.1). It is known for its rich historical and archaeological sites, including the famous Karak Castle. The governorate covers about 3,495 square kilometers and is characterized by diverse geographical features. Al-Karak Governorate is between longitudes (35° 19'

30") and (36° 13' 51"), and between latitudes (30° 47' 26") and (31° 27' 45") and the center of the province is 130 km south of the capital Amman according to (The Department of Statistics, 2022). Al-Karak governorate in southern Jordan, has a population of around 316,629, according to the Department of Statistics in Jordan's 2021 census.

The geography of Al Karak Governorate is predominantly mountainous, with the eastern part of the governorate being part of the rugged Al-Sarhan Plateau. The region is intersected by several wadis (valleys) that contribute to the drainage system of the area. The most prominent wadi is Wadi Al-Mujib, which runs through the governorate and eventually reaches the Dead Sea.

The cities in the governorate are located at elevations ranging from over 1000 meters above sea level in the South Mazar Department to 800 meters above sea level in the northern departments to about 330 meters below sea level at Ghor Al-Safi Department. The governorate is connected to the rest of Jordan by two highways:

The landforms present in these macro-geomorphic units allow differentiating, at different scales, five morphoclimatic areas: semi-arid and hyper-arid, mountainous areas, Very low areas approximately 400 below sea level The Mediterranean climate prevails in the mountainous highlands, where the winter is characterized by cold, and rainfall ranges from 200 to 400 mm, while the summer is dry and hot, and there is a subtropical climate in the Jordan Valley regions, which is characterized by being drier and hotter than the central and northern valleys. , And that the area of traffic agricultural land is much less than the northern Jordan Valley, due to the scarcity of water and the dams that supply the area. The climate of the study area is characterized as a Mediterranean climate, with hot and dry summers and relatively mild winters. The

governorate experiences limited rainfall, which mostly occurs during the winter months. Due to its geographical location, Al Karak Governorate is subject to various climatic influences, including the Mediterranean Sea to the west and the Arabian Desert to the east. Agriculture plays a significant role in the economy of Al Karak Governorate, with the cultivation of crops such as olives, grapes, and vegetables. Livestock farming, including sheep and goats, is also prevalent in the region. Water resources, including groundwater and surface water, are essential for supporting agricultural activities and sustaining the local communities.

The geography of the study area, with its mountains, valleys, and limited water resources, influences various aspects of life, including land use patterns, economic activities, and societal dynamics. Understanding the geographical context of the study area is crucial for conducting a vulnerability assessment of water resources to climate change using GIS and RS. It provides insights into the specific challenges and opportunities related to water resource management and adaptation strategies in Al Karak Governorate.

1.4.1 Study area: selection and importance

Al-Karak was chosen as the study area because it is vulnerable to climate change due to its geographical location and the associated meteorological, hydrological, and socioeconomic characteristics (MWI, 2016). In particular, the area is characterized by random withdrawal of water for human use (Agricultural, Excessive pumping of the groundwater, and Deterioration of water quality) and mismanagement of water resources and thus needs urgent attention (Salameh, 2008). According to the study of Abdullah et al. (2018), this study was conducted in Al-Karak Governorate, which assessed the impacts of climate change on water resources

availability. The study emphasizes the significance of investigating the vulnerability of water resources in this particular region, given its geographical location, hydrological characteristics, and potential climate change risks. To reduce the impacts of climate change on water resources, the study area is suitable for the following reasons: The existence of at least one meteorological and hydrological station for each sub-catchment and the existence of long-term measurement records at the station.

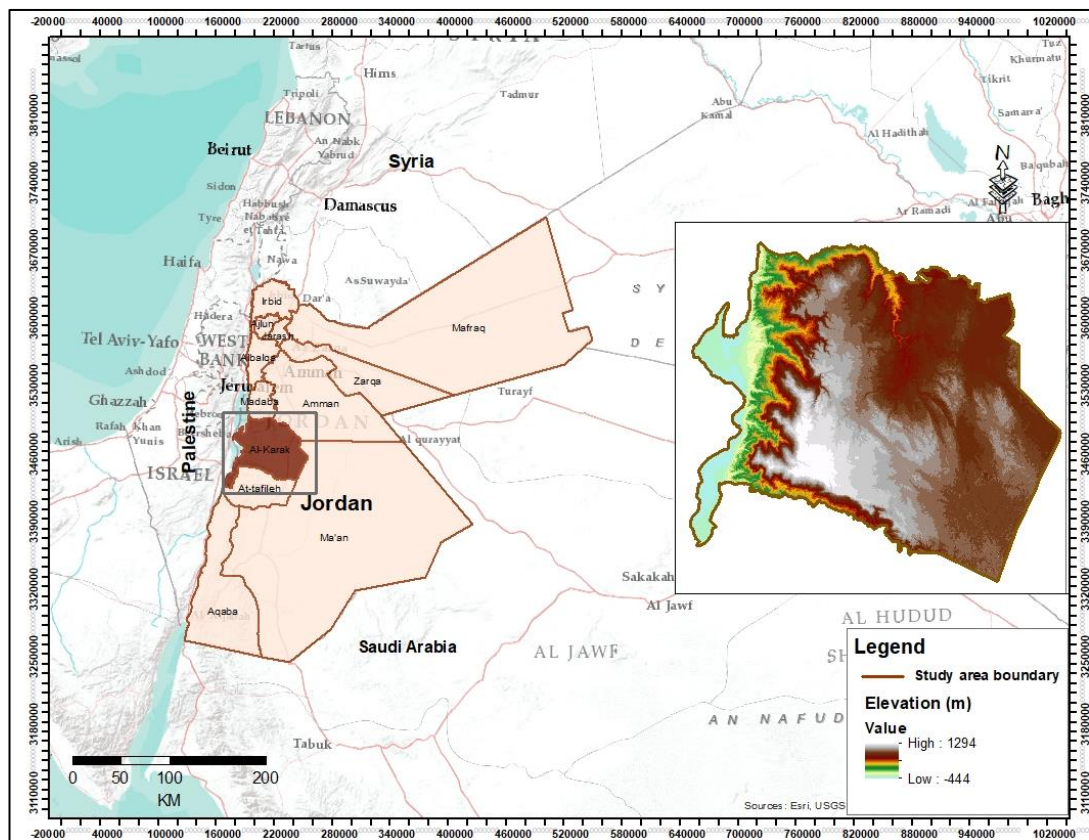


Figure 1.1 The study area location

1.5 Research Objectives (RO)

This study aims to propose a model that can provide information for enhancing decision-making in vulnerability assessment of water sources in the semi-arid region.

The following objectives were set to achieve the aims of this study:

- RO1** To determine spatial factors that can contribute to the vulnerability of water resources in the study area using AHP.
- RO2** To develop a vulnerability index of water resources for a semi-arid region.
- RO3** To validate the Water Resources vulnerability index map in the study area.

1.6 Research Questions (RQ)

The research will attempt to answer the following main questions:

- RQ1** What are the spatial factors that can contribute to the vulnerability of water resources in the study area using AHP?
- RQ2** What is the best model assessment for developing a vulnerability index of water resources for a semi-arid region?
- RQ3** How to validate the Water Resources vulnerability index map in the study area?

1.7 Research Significance

The importance of this study lies in showing how the vulnerability index can provide information and a description of the issue of water resources being affected by climate change and the extent of the impact of climate change. These changes exert

pressure on water resources, change spatially and temporally, and cause several imbalances between supply and demand in hydrological systems. These systems are particularly vulnerable to these changes due to their limited adaptive capacity, which could create significant challenges for future water resource management. Therefore, the information generated can be used to enhance decision-making and policy formulation. This study is important, especially in the management and adaptation of water resources, as it studies the current water situation and options for adaptation and resilience of water in the study area. In addition, this study developed a Vulnerability index that contains all the factors that involve and control the impact on water resources of climate change in the study area. This study will contribute to filling the research gap by providing a comprehensive assessment of water resource vulnerability to climate change using GIS and RS techniques. In this study, Geographic Information Systems (GIS) and Remote Sensing (RS) are utilized as essential tools for assessing water resource vulnerability in Al-Karak, Jordan, particularly in the context of climate change. GIS enables detailed spatial analysis, allowing for the mapping of various factors such as land use, soil type, rainfall patterns, groundwater levels, and population density. This spatial analysis is crucial for identifying vulnerable regions and understanding the interaction of these factors across the landscape. Additionally, GIS integrates multidimensional datasets, including climatic, hydrological, and socio-economic data, facilitating a comprehensive analysis of water vulnerability. This integration is vital in complex environments like Al-Karak, where multiple stressors contribute to water scarcity. Remote Sensing provides large-scale, up-to-date environmental data, making it invaluable for monitoring land use changes, vegetation cover, and surface water availability in areas with limited ground-based data. This capability is particularly useful for tracking changes over time, especially in response

to climate change. By combining RS with GIS, the study can effectively quantify the impacts of climate change on water resources by monitoring shifts in temperature, precipitation, and other climatic factors. Moreover, these technologies offer efficient and cost-effective data collection and analysis, which is critical for resource-limited regions like Jordan, where extensive ground data collection may not be feasible.

The findings will assist policymakers, water resource managers, and stakeholders in developing strategies for adaptation and mitigation. Additionally, the study will provide a framework for future research in vulnerability assessment using GIS and RS tools.

1.8 Scope of the study

The scope of the study is the adoption of GIS technology in the Alkarak Government which includes all cities within the Local Authority. Which covers an area of 3750.50 km.

The integration of GIS and the Analytic hierarchy process (AHP) is used as a tool to find a suitable Vulnerability Assessment of Water Resources to Climate Change selected by the decision-makers. Selected three types of indicators: exposure, sensitivity, and adaptive capacity involved in reviewing available scientific, socio-economic, and development policies and publications, existing databases, and consultation with the local community.

Weights for each criterion are determined through pairwise classification and comparison methods. This aims to obtain a score on the Assessment of Water Resources to Climate Change. Analysis of the vulnerability of water resources to climate change is limited to GIS and AHP capabilities through Arcmap10.8 software.

1.9 Thesis Organization

This thesis consists of five chapters which are described in brief as follows:

Chapter 1: INTRODUCTION

Provide an overview of this study, the techniques that will be used in this research, and the target study area. This chapter presents a brief background to the study area in terms of geography and location. In addition, statements of the problem, the objectives, the Research Questions, and the Research Significance of this study are also presented in this chapter.

Chapter 2: LITERATURE REVIEW

Consists of two parts. The first part presents a summary of the causal factors of landslides. The second part reviews the previous studies on landslides by using RI, DEM, and GIS techniques.

Chapter 3: METHODOLOGY

Devoted to techniques, materials, and methodology. This chapter discusses the basic principles and programs of the three techniques GIS and RS used in this study.

Chapter 4: RESULTS AND DISCUSSION

This chapter begins with a detailed discussion of the methodology used to assess the vulnerability of water resources to climate change, including the data collection process, data processing, and the application of GIS and remote sensing techniques.

The chapter discusses the calculated indices representing each aspect of vulnerability, such as the exposure index, sensitivity index, and adaptive capacity index. These indices provide quantitative measures of the vulnerability of water resources in the study area to climate change.

The chapter includes detailed maps, graphs, and visual representations of the vulnerability assessment results, using GIS, AHP, and RS data to provide a comprehensive spatial analysis of vulnerability patterns in the study area.

The results are then thoroughly discussed and interpreted in the context of the study's objectives and research questions. The researcher may highlight the areas and sectors that are most vulnerable to climate change impacts on water resources, identify hotspots of vulnerability, and discuss the implications of these findings for water resource management and climate change adaptation strategies.

Chapter 5: **CONCLUSIONS AND RECOMMENDATION**

Consists of two sections. The first section presents the conclusions of this study. The second section involves some suggestions for future works.

REFERENCES

List of all the cited references in the thesis.

1.10 Contribution

This study holds significant importance as it was conducted in Jordan, specifically in the Al Karak area, which is a region facing limited water resources. Jordan is known for being one of the countries with the least availability of water worldwide. The research findings show the impact of climate change on water

resources in this study area. The contributions of this study are notable in terms of theory, practice, and methodology, each discussed in the following sub-section.

Moreover, it is worth mentioning that this study stands out as one of the few conducted in the Jordan region, as well as in similar regions across the world, that attempts to comprehensively integrate all factors influencing and controlling water resources' vulnerability assessment to climate change. As a result, it is the first empirical study in Jordan to develop a model specifically focused on water resources vulnerability assessment in the Al Karak region and similar areas.

The model developed in this study includes a wide range of factors that play a crucial role in water resource sustainability. By incorporating these factors into the assessment, the research offers a holistic and comprehensive approach to understanding and addressing the challenges posed by climate change on water resources in the region.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Vulnerability assessment of water resources and application requires an understanding of various aspects like the concept of vulnerability and vulnerability index, it includes the theoretical framework, literature about Climate change, Climate change Impacts on Water Resources in Jordan, the uses of GIS and RS Applications in Water Resource Assessment, and a literature about the factors used in semi-arid region.

Further, the vulnerability can be best studied in a GIS environment for which a suitable database needs to be developed. This chapter deals with a review of the literature available on the above aspects.

2.2 Climate change

Climate change is defined in differing definitions. The Intergovernmental Panel on Climate Change (IPCC) (2014), defines climate as a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period, typically decades or longer. Climate change can be caused by natural internal processes, external forces, or long-term human changes in atmospheric composition and land use.

Climate change has significant impacts on water resources worldwide, affecting their availability, quality, and distribution. Climate change has significant impacts on water resources worldwide, affecting their availability, quality, and

distribution. Climate change alters precipitation patterns, resulting in shifts in the timing, intensity, and spatial distribution of rainfall and snowfall. This leads to changes in water availability and availability of water resources (IPCC, 2014). Studies have shown that climate change has led to altered rainfall patterns, including longer dry spells and more intense rainfall events, affecting water availability and contributing to droughts and floods (Parvaze et al., 2023; Kusangaya et al., 2021; Shahzad et al., 2021).

Climate change disrupts the natural hydrological cycle, including evaporation, transpiration, and runoff processes. Rising temperatures increase evaporation rates, impacting water availability in rivers, lakes, and reservoirs (Althoff et al., 2020). Additionally, changes in snowmelt patterns affect water supply in regions dependent on snowpack as a water source (Hock et al., 2019). In addition, climate change affects the hydrological cycle, as it creates disturbances in the hydrological cycle. These disruptions in the hydrological cycle have implications for water resources and water management. Climate change-induced sea-level rise leads to the intrusion of saltwater into coastal aquifers and estuaries, resulting in the salinization of freshwater resources (IPCC, 2019). This impacts the availability and quality of freshwater resources, especially in coastal areas (Bosire et al., 2021). Studies have highlighted the vulnerability of coastal aquifers to saltwater intrusion due to climate change impacts (Javadi et al., 2022). Increased Frequency and Intensity of Extreme Events:

Climate change is associated with increased frequency and intensity of extreme weather events, such as hurricanes, storms, and heavy rainfall (Robinson, 2021). These events can result in flash floods, landslides, and infrastructure damage, affecting water availability, quality, and storage capacity (Zhao et al., 2022). Numerous studies have

highlighted the influence of climate change on extreme events and their impact on water resources (Kundzewicz et al., 2020; Tabari, 2020; Schilling et al., 2020).

2.3 Climate Change, Change on the MENA Region

The Middle East and North Africa (MENA) region has an arid to semi-arid climate with one of the world's lowest per capita water supplies. Simultaneously, the region is rich in fossil fuels, resulting in a continuously increasing industry as well as rising water and power consumption a result, the area currently has the world's fastest-growing rate of emissions, accounting for 4.5 percent of global greenhouse gases (GHG) worldwide (EcoPeace Middle East, 2019).

However, as a result of climate change, MENA will become substantially warmer by 2030. The average summer temperature in the MENA region is anticipated to rise by 1-2 °C by 2050 and beyond (Tull, 2020). In various geographic regions, the average annual water availability is around 7000 m³/ person, whereas the MENA region experiences a significantly lower water availability of only 1200 m³/person/year. This region holds the highest rates of per capita freshwater extraction globally. Due to a growing population and rapid economic expansion, it is anticipated that per capita water availability will decrease to alarming levels in the coming decades (Namdar et al., 2021). According to the World Water Development Report 4, water scarcity stands as a major threat to the economies of MENA countries (Arezki et al., 2018). Approximately 1% of GDP in Egypt, Jordan, Lebanon, and Morocco, and nearly 3% of GDP in Iran are allocated to address water-induced health issues and the loss of agricultural products (Fouda et al., 2015). The persistent water scarcity in these countries could lead to severe economic consequences shortly (Arezki et al., 2018).