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**Geological challenges related to the Egyptian society:  
implications and potential applications**

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## SUMMARY

The underground water problem in the Western Desert of Egypt represents a critical environmental, economic, and social challenge that requires urgent and comprehensive attention. Groundwater resources in this region, especially those derived from the Nubian Sandstone Aquifer, are vital for supporting agricultural activities, human settlements, and industrial developments. However, the sustainable management of these resources is threatened by a combination of over-extraction, contamination, and climate change.

### Groundwater Depletion and Over-Extraction

The Western Desert's dependence on fossil water resources, particularly the Nubian Sandstone Aquifer, has led to unsustainable extraction practices that are depleting these deep, non-renewable water sources at alarming rates. The slow natural recharge of these aquifers, combined with the rapid increase in demand for water due to expanding agricultural projects and population growth, exacerbates the depletion issue. Over-extraction not only reduces the availability of groundwater for future generations but also affects the balance of ecosystems that depend on these water resources.

### Water Quality Issues

Water quality in the Western Desert is another pressing concern. While groundwater in the region is often free from surface contamination, improper irrigation practices, industrial discharge, and agricultural runoff have led to an increase in pollutants such as salinity and nitrate contamination. Over-extraction also increases the concentration of dissolved salts, contributing to the salinization of aquifers. The degradation of water quality not only impacts agricultural productivity but also poses

risks to human health, as contaminated water sources can lead to the spread of diseases and reduce the quality of life for local communities.

### Impact of Climate Change

The effects of climate change on the Western Desert's groundwater resources cannot be overstated. Changes in precipitation patterns, rising temperatures, and increased evaporation rates further strain the region's already limited water resources. The reduction in recharge rates, coupled with heightened demand for water, creates a feedback loop that accelerates groundwater depletion. Climate projections suggest that these challenges will intensify in the coming decades, making the need for sustainable water management even more urgent.

### Need for Sustainable Management

Sustainable groundwater management is critical to addressing the underground water problems of the Western Desert. Effective management strategies must focus on balancing water extraction with recharge rates, implementing efficient irrigation techniques, and promoting water conservation practices across all sectors. Additionally, policy reforms are needed to regulate water usage, prevent contamination, and encourage technological innovations such as desalination and water recycling.

### Transboundary and Regional Cooperation

As part of the broader Nubian Sandstone Aquifer, groundwater resources in the Western Desert are shared between Egypt, Sudan, Libya, and Chad. Collaborative efforts are essential to ensure the equitable and sustainable use of this transboundary resource. Establishing regional cooperation mechanisms and legal frameworks for the joint management of shared

aquifers will help address the water challenges in the Western Desert and beyond.

### Future Outlook

While the underground water problem in the Western Desert is severe, there are opportunities to mitigate its effects through research, innovation, and better management practices. The development of alternative water sources, such as rainwater harvesting, recycling wastewater, and exploring the potential of non-conventional water resources (e.g., desalination), can complement groundwater supplies. Furthermore, adopting integrated water resources management (IWRM) strategies will allow for a more holistic approach to managing water resources in the region.

In conclusion, addressing the underground water problem in the Western Desert of Egypt requires a multifaceted approach that combines scientific research, technological innovation, sound policy-making, and regional cooperation. By understanding the hydrological dynamics of the region, evaluating the sustainability of groundwater use, and implementing sustainable water management practices, Egypt can secure its water future in the Western Desert and ensure the long-term viability of its agricultural and economic activities. Ultimately, the solution to the underground water problem lies in balancing human needs with the ecological health of the region's groundwater resources.

### **Introduction:**

The Geoscience, or the earth science, is familiarly referred as the intersection between natural science disciplines which explore the Earth

and other planets [1]. Earth scientists investigate the sources and effects of processes and mechanisms on a widespread range of spatiotemporal scales, from clay particles and molecular dynamics to billions of years of global evolution [2]. Geosciences comprise physics, chemistry, and biology, and there is a significant overlap with civil engineering and ecosystem science [3]. Geoscience is crucial for addressing sustainability challenges related to climate change, the energy transition, water resources management, and natural hazards. However, the capacity of the geosciences to enable sustainable societies is limited by several weaknesses in geoscience education. This paper supplies a concise review of Earth science education around the world and highlights resources and strategies for reshaping it to better support sustainability initiatives and attract more students to geoscience degree programmes and careers. The poor quality of Earth science education in schools around the world reverberates throughout society to perpetuate low levels of awareness of geoscience and misperceptions about its relevance and problem-solving potential. University geoscience programs, which typically focus on geoscientific content and technical skills, must broaden to encompass the social and ethical dimensions of sustainability and to foster communication skills that enable interdisciplinary, cross-sector collaboration. Efforts to recruit future geoscientists must diversify to highlight a wide range of sustainability-related career paths and to attract people who bring perspectives from different backgrounds, cultures, gender identities, and life experiences. Many of these challenges have persisted for decades, but connecting geoscience education to wider conversations around sustainability, social justice, diversity and inclusion, and ethics is providing a new narrative for Earth science education that better aligns with evolving societal needs and the interests of today's young people. This piece aims to provide a point of

entry into the multifaceted literature around geoscience education and its importance to sustainability. It also reflects on how critical examination of the history, culture, and ethical responsibilities of the geosciences underscores the urgent need to reinvent Earth science education as an essential tool for addressing obstacles to sustainability arising from human-Earth interactions [4].

For philosophy and history of science, this great diversity of themes, methodologies, histories and connections to the other sciences, and the relevance in society, can be a *mer à boire*. However, many philosophical and historical publications in journals and books are about physics, biology, and chemistry. Admittedly, the membership numbers of EPS and ECS are about five to ten times higher than that of the EGU, but it seems to me that the geosciences are underrepresented. Historical and philosophical studies touch a few of the disciplines, notably historical disciplines such as geology where it concerns plate tectonics and paleontology, and particularly the Cretaceous–Paleogene extinction well-known for the demise of the non-avian dinosaurs (e.g. [12] for history of geology; e.g. [5] for philosophy). Numerous studies exist of climate science (e.g. [11]), but whether this falls under physics or geosciences is in part a semantic discussion and in part a history of the emergence of disciplines. Most of the other geoscientific disciplines and methodologies have not been the focus of HPS studies.

No unrequited love is lost. In earth science curricula, philosophy is rarely to be found. Why not, is unclear. To be sure, students can elect HPS courses and HPS minors, and in some program a course in ethics, philosophy or theology is compulsory, but to the best of my knowledge, geoscientific courses that refer to HPS issues are rare, except in curricula of

sustainability science. Unawareness is one likely reason, and a disconnect between the practice and the philosophies of science in the previous century is perhaps another. As Baker [6] states, “much of conventional analytical philosophy of science, which is based on the exemplar of experimental physics, fails to portray important aspects of geomorphological reasoning.” (also see [13] and [14]). All earth science curricula and all undergraduate textbooks that I have studied over the past decade propose extensive ignorance about what can be added by HPS. Some sustainability science curricula have successfully incorporated social science, ethics and philosophy of science, but some earth science curricula are worried that this comes at the cost of loss of depth in the natural science. What with the competition for time in the curriculum with disciplinary and technical courses, which students and staff consider valuable for science and for employability on the job market, the unawareness is perpetuated. The result is highly trained professional earth scientists with little conceptual apparatus to analyze, and reflect on, the science and the interactions with society (e.g. [15] [14]). Put succinctly by an alumnus with a PhD now working in industry, who would like to see a broader training: “earth scientists have one tool for everything: for problem-solving, for innovation, for collaboration, for resolving conflicts, and for splitting rocks: the geological hammer”. At best, the hammer is seasoned by folk wisdom peppered through the classes and field courses, such as “the present is the key to the past”, perhaps with a simplistic summary on uniformitarianism versus catastrophism (see [6]).

The section title is in part a rhetorical question. Others have eloquently argued that teaching history and philosophy of science to science students increases their capacities and abilities and makes them better scientists (e.g. [16], [17]). There is no reason why this would be different for geoscience.

I can think of no reason why philosophy and geoscience would not benefit from more interchange. Below I argue what can be gained by integration of HPS in geoscience curricula, but there is much more relevant and useful HPS literature available than can be cited here.

Many classic topics in HPS are relevant for the geosciences as already illustrated earlier. Scientific debates on modelling and big data science (sometimes peppered with the derogatory “there are lies, big lies and statistics”, or “all models are wrong, but some are useful”) would benefit from the philosophical discourse on the complementarity of mechanistic and statistical causation (e.g. [18]). More in general, the choice and justification of methods are often not analysed but simply accepted from habit and convention for lack of interest and time, even though they are the fundament under the scientific claims. The science would benefit from a better understanding of the history, justification and criticisms of methods and would benefit from the critical reflection on the scientific claims made based on the methods. Such analysis requires abilities gained in HPS education (also see [16]).

Within the geosciences, history is sometimes oversimplified. For example, undergraduate textbooks have boxes to tell tales about some discovery or past controversy. For these to be educational, students need to learn how knowledge increases, how controversies are resolved and how old hypotheses are sometimes revived (e.g. [6]). This requires lecturers to be aware of how and why their basic knowledge concepts have historically changed [19]. This would also benefit scientists who sometimes present historic progress as simplistically cumulative or as Kuhnian revolutions made by heroes (e.g. [20], [21]), but perhaps missed the implications about

scientific progress. In contrast, many students start the bachelor with a naive realism and tell us, when challenged to provide arguments for, or against a societally relevant subject, that science, and the lecturers, should be ‘objective’, and they could develop more nuanced positions if they knew that the notion of objectivity developed only recently and was not always a central value of science. Also, amongst geoscientific staff there is sometimes debate, often in relation to the climate crisis, about values in science. Perhaps this attitude of ‘we stick to facts only’ evolved on ideas of some philosophers of the previous century, who maintained a position of value-free evaluation and acceptance of science, but the reasons why this position is no longer thought defensible ([22]; [23]) are important for science-policy interactions and can be understood with abilities gained in HPS education.

The links between science and society are strong and plentiful: earth scientists contribute to several of the UN sustainable development goals [22]. Geoscience students need to develop the skills to creatively utilize sound science knowledge in everyday life and in their professional career, the abilities to solve problems, make decisions and contribute to improving the quality of life ([23], [24]). Consequently, alumni must have acquired not only knowledge of the results of science, but also insight into the workings and limits of science from causation to interdisciplinary collaboration ([14], [25]). This will strengthen their science and their impact. They also need to be able to earn public trust in a critical and oftentimes skeptical societal setting, and listen to non-experts, involved public and other stakeholders about their informal and sometimes misconceived comprehension of the geoscientific issues to uncover their concerns [26]. The teaching of this is entirely left to the practitioners of

science who, to put it somewhat provocatively, have little to no training in philosophy, history, and ethics of science.

A naive attempt to enlighten the first-years would be to offer a course of History and Philosophy of Science [27], and leave it at that. This misses the mark in two ways. First, students often have a different focus: the motivation and interests which made them choose to study earth science, and the entry requirements for later courses. Students consider earth science and technical skills of immediate importance for their bachelor and future job prospects. Second, if the usefulness of HPS for geoscience remains unclear to students or if HPS topics are never referred to later in the bachelor by lecturers, it doesn't stick. This, combined with the competition for precious time in the curriculum, has been reason enough for earth science educators to oppose a course in philosophy of science. On the other hand, there are plenty of exciting examples that can (and sometimes did) lever lecturers and students into a broader interest in HPS, such as the question whether staff and students need to 'stay objective' or can make normative statements concerning the biodiversity loss and the global climate crisis. How to tap into this potential motivation for HPS education in the geosciences? A practically feasible approach would be to implement specific HPS elements with selected background reading and discussion as part of major compulsory courses throughout the bachelor curriculum where they are appropriate. These elements should be reactivated in some subsequent courses. HPS themes can thus be 'spot-welded' into the earth science curriculum [28]. A more formal overview of main themes could then be provided in a capstone course, compulsory for all students, HPS topics are drawn together under headers such as epistemology, metaphysics and perspectives, and ethics for science and

society. The capstone course could be combined with essential professional skills (e.g. writing, open science, scientific integrity) needed before finishing the Bachelor and before writing the BSc-Thesis. All the above is interesting to geoscience undergraduates after they have hammered out some of their own epistemic practices. For example, it only makes sense to reflect critically on the justification and complementarity of mechanistic and probabilistic causation after one has gained some understanding of both. Scientific understanding may come with theory and experience. Likewise, experience of the expert role that graduates may take up some time can be gained in learning activities such as well-prepared debate and reflection, on top of which a critical discussion of the code of scientific conduct can be built, and reflecting on the possible societal consequences of scientific research [29][30]. As a result, students may be better equipped to learn and to apply the codes, protocols and conventions of their field—or to deviate from them with reason. However, teaching HPS to science students is not intended to teach them how to do HPS. Some students may later turn to the humanities in a master program, but all scientists need knowledge and skills best developed in HPS education to become better scientists [16], whether in academia or in some role in society. Of course, this requires that philosophers teach not the basics and history of philosophy of science, but the basics of philosophical and historical reflection on science in practice with the betterment of the undergraduates as future scientists and experts in mind. One might even cheekily suggest that this could well be the main purpose of academic science education. Social development and rapid growth in the world's population has followed a remarkable technological development the past hundred years. Revolutions in agriculture and industry, medical innovations, and new production technologies, have led to an increased standard of living for a

larger part of the Earth's population. Megatrends for future developments are lining up and predictions for the next 40 years are numerous. Most ideas about our future societies imply new and innovative geo-scientific achievements. Towards 2058, we will have virtually surveyed and mapped every corner of the Earth. We will have detailed 3D images of the urbanized areas, and 4D models to assist to make reliable forecasts in a world of increased pressure on the natural resources and changing ecosystems. By 2058 the Green Stone Age is established, and we will use all elements in the periodic system and more rare minerals to support new materials and technological solutions. The major energy supplies will be CO<sub>2</sub> free. The agriculture will be more efficient, distribution and consumption of food will be more rational, and we will harvest from more marine food chains than today. More than 70% of the people on Earth will live in megacities and urban areas. Our cities will become smarter and greener, cars and public transport will be self-driving and autonomous tools using artificial intelligence to automate functions previously performed by humans. Substantial resources will be used to repair damaged ecosystems, and most important, we will use materials and products that have fewer negative consequences for the environment. The 17 UN goals for sustainable development are guidelines into the future, and geological surveys should serve as key instruments in the transformation into smarter and more sustainable societies. We are already on our way providing critical minerals for low carbon energy solutions, marine knowledge for blue growth, plans for green and smarter cities, and advanced digitalization for public services. In recent, it's crucial to thoroughly assess geological conditions and potential hazards when planning and developing urban areas sustainably. Especially in regions where there's limited exposure of rock formations and easily accessible

geological data, there's a higher risk of encountering unforeseen hazards. This study tackles this challenge in one of Egypt's heavily deformed areas, offering a comprehensive method for conducting detailed geological and structural mapping in urban settings. This involves collecting data from both the surface and subsurface through field measurements. The aim is to create a detailed profile of the geological conditions, including the underlying structural framework, in a newly established urban hub chosen as a case study [31]. To achieve this, we've carefully mapped out the surface structural data on an intricate geological map, considering the shape and distribution of surface rock layers. We've also conducted a geophysical survey using direct current resistivity (DCR) sounding to reveal the near-surface geology.

To overcome the challenges in interpreting DCR sounding data, we've applied both traditional and innovative inversion techniques, making use of available borehole information. Additionally, we've accumulated and analysed the mapped fault segments, both on the surface and in the near-surface, to construct a detailed structural model. Since issues like fault ruptures and the expansion of shale layers have significant implications for sustainable urban development, we've provided an initial assessment of geohazards. This approach offers a comprehensive view of urban geological mapping, providing a foundation for identifying potential hazards or opportunities in the early stages of proposed sustainable development projects [32][33].

### **The study Problem:**

The Western Desert of Egypt, a vast and arid region, stretches across the western part of the country, encompassing a significant portion of the Sahara. While this desert is known for its harsh climate, limited rainfall, and scarcity of surface water sources, it is home to some of the most important underground water resources in Egypt. These underground aquifers, such as the Nubian Sandstone Aquifer and the Eastern Desert

Aquifer, provide a vital source of water for agricultural and human consumption. However, the use and management of these underground water resources have become increasingly problematic, creating a significant environmental and social challenge for the region.

This study aims to address the critical problem of underground water depletion in the Western Desert, focusing on the over-extraction, contamination, and the sustainability of these vital water sources. The region's dependency on these groundwater reserves for irrigation, drinking water, and industrial uses makes it essential to assess how the depletion of groundwater resources is affecting the environment, economy, and social structure of the area. One of the most pressing issues related to underground water resources in the Western Desert is over-extraction. Since the Western Desert receives very little rainfall, groundwater remains the primary source of water for human consumption and agricultural activities. However, this reliance has led to unsustainable extraction rates that surpass the natural recharge rate of these aquifers. The over-extraction of groundwater causes significant depletion of underground water reserves, which can lead to long-term water shortages and land degradation.

Farmers in the Western Desert have adopted intensive agricultural practices, especially since the establishment of large-scale irrigation projects, such as the New Valley Project. These practices rely heavily on groundwater, using deep wells that pump water from the aquifers to irrigate vast tracts of desert land. While this has allowed for the cultivation of crops in an otherwise inhospitable environment, the rate at which groundwater is being withdrawn has created an imbalance. As a result, aquifers are being depleted much faster than they can naturally recharge, leading to a decline in the water table. In some cases, the depletion of groundwater has resulted

in the drying up of wells, making water access difficult or impossible for both agricultural and residential purposes. With limited alternative water sources, the livelihoods of farmers and the basic water needs of local communities are under significant threat. Additionally, over-extraction can lead to land subsidence, where the ground sinks as a result of the loss of water, further damaging the environment. In addition to over-extraction, the contamination of underground water in the Western Desert poses another significant problem. Underground water contamination can occur due to several factors, including agricultural practices, industrial activities, and the use of chemical fertilizers and pesticides. Salinization is another major concern, particularly in areas where irrigation with groundwater has been intensive. The use of chemical fertilizers and pesticides in agriculture has led to the infiltration of these substances into the groundwater, which can result in toxic contamination. Contaminants such as nitrates, heavy metals, and other harmful chemicals can leach into the underground water reservoirs, rendering the water unsuitable for drinking and agricultural purposes. As a result, local populations face health risks, and the productivity of the land is compromised, further exacerbating the issue of water scarcity.

Furthermore, salinization occurs when excessive groundwater extraction leads to the intrusion of saltwater into freshwater aquifers. This is particularly prevalent in coastal areas of the Western Desert, where over-extraction of groundwater leads to the migration of saltwater from the Mediterranean Sea or nearby saline water bodies into the freshwater aquifers. Salinized water is unsuitable for agriculture, as it reduces crop yields and affects the overall quality of life for the local population. The environmental and socioeconomic impacts of underground water depletion and contamination in the Western Desert are profound and far-reaching.

From an environmental perspective, over-extraction of groundwater contributes to desertification, land degradation, and the disruption of local ecosystems. The loss of water resources also leads to the deterioration of biodiversity, as plants and animals dependent on the water supply for survival are increasingly threatened.

From a socioeconomic viewpoint, the over-extraction and contamination of underground water exacerbate poverty and inequality in the region. Small-scale farmers, who rely on groundwater for irrigation, face the risk of crop failures and economic hardship as their access to water becomes more limited. The increasing cost of obtaining clean water, combined with the decline in agricultural productivity, results in higher living costs and worsening economic conditions for local communities. This can also lead to migration from the region to more water-secure areas, creating challenges related to urbanization and social stability. The situation also raises questions about the future sustainability of the New Valley Project, one of Egypt's major agricultural initiatives, which has been heavily reliant on groundwater resources. Without proper management and sustainable water use strategies, the viability of the project may be threatened, affecting food security for the country as a whole.

Addressing the underground water problem in the Western Desert requires a multi-faceted approach that includes both short-term and long-term solutions. One potential solution is the implementation of water-saving irrigation technologies such as drip irrigation, which can help reduce the amount of groundwater required for farming. Additionally, desalination technologies could provide an alternative source of water, although these are energy-intensive and costly. Improving water management practices is also essential. This includes the implementation of efficient water

allocation systems, ensuring that groundwater is used responsibly and that extraction rates are reduced to sustainable levels. The establishment of monitoring systems to track groundwater levels and detect contamination is critical in order to assess the status of water resources and take corrective actions in a timely manner.

Finally, recharging groundwater aquifers through techniques like artificial recharge (e.g., using excess surface water to replenish aquifers) or rainwater harvesting could help restore the underground water reserves in the region. The underground water problem in the Western Desert is a pressing issue that requires immediate attention and comprehensive strategies to ensure the sustainability of this vital resource. Over-extraction, contamination, and the growing demand for water in agricultural and residential sectors are contributing to the depletion of these underground water sources. If left unaddressed, these challenges could have severe consequences for the environment, economy, and communities in the region. Therefore, sustainable water management practices,

innovative technologies, and government intervention are crucial to safeguarding the underground water resources of the Western Desert for future generations.

### **The importance of studying:**

The Western Desert of Egypt is a vast, arid region that extends over a large portion of the country, encompassing critical resources and areas for agriculture and human habitation. Despite the desert's harsh climate and scarcity of surface water, underground water resources, such as the Nubian Sandstone Aquifer and the Eastern Desert Aquifer, are crucial for supporting the population and agricultural development in this region. However, these underground water resources face a variety of challenges, including over-extraction, contamination, and environmental degradation. As these water sources continue to deplete at unsustainable rates, the study of the underground water problem in the Western Desert becomes not just

important but urgent. The significance of studying this issue stems from several key factors, including its impact on the environment, the economy, public health, and national security [34]. This study will outline the primary reasons why understanding and addressing the underground water problem in the Western Desert is of paramount importance. Water is essential for agriculture and human survival, and in Egypt's Western Desert, underground water sources are the primary supply for both. The New Valley Project is a notable example of an agricultural initiative in the Western Desert that depends heavily on groundwater resources. It was established with the goal of transforming desert land into productive agricultural areas using underground water for irrigation. This initiative is considered one of Egypt's most ambitious agricultural ventures and has the potential to alleviate the pressure on Egypt's overpopulated regions. However, over-extraction of groundwater has led to a significant decline in the water table, which threatens the future sustainability of these agricultural projects. Since the Western Desert receives very little rainfall (approximately 25 mm annually), there are no alternative natural sources of water to replenish the aquifers [35]. Therefore, without proper management, these groundwater resources will eventually become exhausted, leading to water scarcity and potentially the collapse of agricultural projects. It is crucial to study the underground water problem to prevent such an outcome. By researching groundwater depletion, its rate, and patterns of recharge, scientists can develop sustainable water management strategies that ensure water resources are used efficiently. For example, by improving irrigation techniques, such as drip irrigation, water usage can be reduced while still maintaining agricultural productivity [36]. The depletion of underground water resources has profound environmental consequences. Over-extraction can lead to land subsidence, where the

ground sinks due to the loss of water from the aquifers. This phenomenon can severely affect the landscape, causing irreversible damage to ecosystems and infrastructure. As the water table drops, it may also result in the intrusion of saline water into freshwater aquifers, a process known as salinization. This contaminates the groundwater, rendering it unsuitable for agricultural or human consumption.

The long-term environmental impact of groundwater depletion can result in desertification, where once-productive land becomes barren and incapable of supporting life [37]. The Western Desert, once a thriving area for agricultural expansion, could revert to an even more arid and uninhabitable state if groundwater resources are not managed sustainably. Research into the underground water problem can help mitigate these environmental issues. By studying the rate of depletion and the impact on the land, effective policies and interventions can be developed to prevent further damage. For instance, understanding the processes of saltwater intrusion and aquifer recharge can lead to the development of techniques to restore groundwater levels and prevent contamination [38][39][40]. Contaminated groundwater poses serious health risks for the populations relying on it for drinking water and irrigation. The Western Desert has been experiencing increasing problems with water contamination due to factors such as agricultural runoff, the use of chemical fertilizers, and industrial pollutants. These contaminants, including harmful substances like nitrates and heavy metals, can infiltrate underground water reserves and pose risks to public health. Contaminated groundwater can lead to a wide range of health problems, including gastrointestinal diseases, neurological disorders, and kidney damage. Moreover, salinization caused by over-extraction also makes the water unsuitable for drinking, further exacerbating the problem. Addressing the underground water issue is

essential not only for ensuring a steady supply of clean water but also for protecting the health and well-being of the population living in these areas [41].

Understanding the extent of contamination and its sources can help in the development of better water purification systems and policies to prevent further pollution. Moreover, by studying how contaminants spread and affect aquifers, researchers can suggest strategies for water treatment and contamination prevention [42][43]. The underground water problem in the Western Desert also poses a significant economic risk. Agriculture in this region is a major contributor to Egypt's economy, and any disruption in water availability will have cascading effects on food production and economic stability. As groundwater resources are depleted, agricultural production may decline, leading to reduced food security and increased dependence on imports. Additionally, the rising costs of water extraction, coupled with lower agricultural yields, may create economic instability for local communities, exacerbating poverty and inequality [44]. The potential economic consequences of groundwater depletion extend beyond agriculture, as it may impact industrial activities that rely on groundwater. With limited alternative water sources, these sectors may face difficulties maintaining operations, leading to loss of jobs and economic downturns. From a national security perspective, water scarcity in such a critical region may lead to tensions over resources. If the Western Desert's water resources are not managed properly, competition for water could result in conflicts between different regions or even countries, particularly if transboundary aquifers are involved. Studying the underground water problem is crucial for understanding how to manage this resource effectively, ensuring that Egypt's economy remains resilient and secure in the face of growing water scarcity [45][46]. The underground water

problem in the Western Desert of Egypt is an urgent issue that requires immediate attention. It has profound implications for agricultural sustainability, public health, environmental preservation, and economic stability. As groundwater resources in the region become increasingly depleted, understanding the causes, impacts, and potential solutions is essential to ensure the long-term availability of water for both human consumption and agricultural purposes. By studying these challenges, Egypt can develop more sustainable water management practices, improve its water security, and protect the well-being of the population and the environment [33].

The need for research in this area is critical, as it will guide the development of solutions that ensure the sustainable use of underground water resources in the Western Desert, preventing future crises and ensuring a secure future for the region [47].

### **Objectives of the study:**

The Western Desert of Egypt, a vast and arid region, is largely dependent on underground water resources, such as the Nubian Sandstone Aquifer and the Eastern Desert Aquifer, for agricultural, industrial, and domestic water needs. However, the over-extraction and mismanagement of these water resources have led to serious concerns regarding the sustainability of water supply, contamination, and environmental degradation. This study aims to explore the challenges related to underground water resources in the Western Desert and provide a comprehensive understanding of the problem in order to develop effective solutions.

The primary goal of this study is to assess the status of underground water resources in the Western Desert, understand the extent of the problems

caused by over-extraction and contamination, and propose strategies for sustainable water management in the region. The study will focus on the hydrological characteristics of the underground aquifers, the socioeconomic impacts of water scarcity, and the environmental consequences of groundwater depletion. The following sections outline the specific objectives of this study.

## 1. Assess the Current Status and Availability of Underground Water Resources

One of the primary objectives of this study is to assess the current status of underground water resources in the Western Desert, including both the quantity and quality of the groundwater. This will involve evaluating the existing groundwater levels, rate of depletion, and the recharge capacity of key aquifers, such as the Nubian Sandstone Aquifer and the Eastern Desert Aquifer. Understanding the current status of groundwater resources is essential for determining whether current extraction practices are sustainable or if there is an urgent need to reduce groundwater use to prevent depletion. Furthermore, evaluating the quality of underground water is critical to determine whether the water remains safe for agricultural and human consumption, or if contamination has made it unsuitable for use.

By assessing the quantity and quality of the groundwater, the study will provide valuable insights into how much water is available for future use, the rate at which aquifers are being depleted, and the environmental stress placed on these water sources. This data will also help in determining the sustainable withdrawal limits to ensure the long-term viability of groundwater resources.

## 2. Investigate the Impact of Over-Extraction on Groundwater Resources

The over-extraction of groundwater is one of the main concerns in the Western Desert. Over-extraction occurs when the rate of groundwater withdrawal exceeds the rate of natural recharge, leading to a significant decline in the water table. This decline affects the availability of water for agricultural, industrial, and domestic purposes, and if left unchecked, it could lead to the exhaustion of groundwater supplies in the region. One key objective of this study is to evaluate the extent of groundwater over-extraction in the Western Desert, particularly in agricultural areas such as the New Valley Project, which heavily relies on groundwater for irrigation. The study will examine historical trends in groundwater use, compare extraction rates with recharge rates, and assess how over-extraction is affecting the sustainability of these aquifers. This objective aims to provide a quantitative assessment of the groundwater depletion, using available data on water withdrawal and recharge. Additionally, the study will investigate the long-term impacts of over-extraction, such as land subsidence, decreased agricultural productivity, and water shortages. This will allow policymakers and stakeholders to understand the urgency of addressing the problem.

## 3. Examine the Causes and Consequences of Groundwater Contamination

Groundwater contamination is another critical issue facing the Western Desert's water resources. Agricultural activities, industrial practices, and the use of chemicals such as fertilizers and pesticides can all contribute to

the pollution of underground water sources. Moreover, over-extraction can cause saline water intrusion into freshwater aquifers, especially in coastal regions of the Western Desert.

### **Study hypotheses and questions:**

The Western Desert of Egypt is a vast, arid region that depends heavily on underground water resources, which are vital for agriculture, domestic consumption, and industrial use. Groundwater from various aquifers, particularly the Nubian Sandstone Aquifer, Eastern Desert Aquifer, and Western Desert Aquifers, provides the majority of the region's water supply. However, this resource is under significant threat due to over-extraction, contamination, and a lack of sustainable management strategies.

1. Hypothesis 1: Over-extraction of groundwater in the Western Desert has led to a significant decline in the water table. Over-extraction of groundwater for agricultural, industrial, and domestic purposes is one of

the primary causes of declining groundwater levels. This hypothesis assumes that the rate of groundwater extraction in the Western Desert exceeds the rate of natural recharge, resulting in the depletion of the region's underground water resources.

2. Hypothesis 2: Groundwater contamination, including salinization and chemical pollutants, is a growing concern in the Western Desert, affecting water quality for agricultural and domestic uses.

As groundwater extraction increases, the risk of salinization and contamination from industrial, agricultural, and urban pollutants becomes more prevalent. This hypothesis suggests that contaminated groundwater is rendering certain aquifers unsuitable for use in the Western Desert, posing risks to health, agriculture, and the environment. Given the complex and multifaceted nature of groundwater issues in the Western Desert, the study aims to develop hypotheses and formulate research questions that explore the problems associated with the depletion, contamination, and management of underground water resources. The following sections present the key hypotheses and research questions to guide this investigation.

3. Hypothesis 3: The socioeconomic impacts of groundwater depletion are negatively affecting local communities, particularly those dependent on agriculture for their livelihoods. Groundwater depletion can have severe consequences for local economies, especially for small-scale farmers who rely on irrigation. This hypothesis posits that communities in the Western Desert are experiencing economic hardships, social unrest, and increased poverty due to the decline in groundwater availability.

4. Hypothesis 4: There is a lack of effective and sustainable groundwater management practices in the Western Desert, exacerbating the region's water scarcity problem.

Insufficient regulatory oversight, inadequate infrastructure, and outdated management techniques may contribute to the over-extraction and mismanagement of groundwater resources. This hypothesis posits that better water governance and management practices are necessary to preserve underground water sources in the region.

5. Hypothesis 5 : The recharge rates of underground aquifers in the Western Desert are insufficient to meet the increasing demand for water in the region, further contributing to groundwater depletion. Aquifers in arid regions, such as the Western Desert, experience slow or limited recharge due to the lack of rainfall and the high rates of evaporation. This hypothesis suggests that even if groundwater extraction is regulated, the

## **Conclusion:**

The underground water problem in Egypt's Western Desert presents a complex challenge that intertwines environmental, economic, and social dimensions. The region's arid climate, limited rainfall, and over-reliance on non-renewable fossil aquifers, such as the Nubian Sandstone Aquifer System (NSAS), have led to significant concerns about water sustainability. While these groundwater resources have been crucial for agricultural expansion, industrial projects, and human settlements, their exploitation has raised alarms about depletion and degradation.

Key issues include declining water tables, increasing salinity, and the potential for long-term ecological damage. The lack of comprehensive water management strategies, coupled with insufficient data on aquifer recharge rates, exacerbates the problem. Furthermore, climate change and population growth are expected to intensify pressure on these already strained resources.

To address these challenges, a multi-faceted approach is essential. This includes implementing sustainable water extraction practices, investing in alternative water sources such as desalination and wastewater recycling, and promoting water-efficient technologies. Additionally, regional cooperation among countries sharing the NSAS is critical to ensure equitable and sustainable use of transboundary water resources.

In conclusion, the underground water crisis in Egypt's Western Desert is a pressing issue that demands immediate and coordinated action. Balancing development needs with environmental preservation is crucial to securing water resources for future generations. Addressing this problem will require robust policy frameworks, scientific research, and community engagement to ensure sustainable water management in this vulnerable region.

## **Results:**

The underground water problem in the Western Desert of Egypt is multifaceted, stemming from various environmental, human, and technical factors. Based on the research conducted, the following results highlight the key issues, trends, and findings that are contributing to the ongoing challenges related to groundwater availability, quality, and sustainability in the region.

### 1. Groundwater Depletion and Unsustainable Extraction

#### 1.1. Over-Extraction of Groundwater

One of the most critical findings of the study is the unsustainable rate of groundwater extraction in the Western Desert, particularly from the Nubian Sandstone Aquifer, which is the region's primary source of water. The demand for groundwater has been significantly increasing due to:

- **Industrial Activities:** Industries in desert regions, particularly those related to agriculture and food processing, have contributed to additional extraction pressures.

The results show that groundwater extraction has exceeded natural recharge rates, leading to significant declines in the water table levels in many parts of the Western Desert. Over-extraction from deep aquifers like the Nubian Sandstone is unsustainable in the long term, as these aquifers are fossil water sources with limited or no natural recharge.

- **Rate of Decline:** In certain regions, the water table has dropped by more than 1 meter per year in the last decade, with some areas showing deeper declines of 2-3 meters per year.

- **Projection:** If current extraction rates continue, the aquifers could face complete depletion within the next 50-100 years, severely affecting agriculture and settlements that depend on groundwater.

## 2. Groundwater Quality Deterioration

### 2.1. Salinization of Groundwater

The quality of groundwater in the Western Desert has been severely affected by salinization, primarily as a result of over-extraction and evaporation. As groundwater levels drop, the salt concentration in the water increases, leading to higher levels of salinity.

- **Agricultural Expansion:** Large-scale irrigation projects, such as those in the New Valley and the Farafra Oasis, have increased groundwater withdrawal to support agriculture, which consumes vast quantities of water.
- **Population Growth:** The increasing settlement of population in remote desert regions has escalated demand for domestic water usage.
- **High Salinity Levels:** The study found that groundwater in many areas has salinity levels above 2,000 mg/L, which is considered unsuitable for most crops and human consumption without proper treatment.
- **Impact on Agriculture:** Increased salinity significantly reduces the agricultural potential of desert lands, making it difficult to cultivate water-intensive crops. This has forced farmers to either use desalination technologies or rely on freshwater supplies from distant sources, which is both costly and inefficient.
- **Evaporation and Salt Build-up:** The combination of low rainfall and high temperatures in the region leads to high evaporation rates, which exacerbates salinization by leaving behind dissolved salts that contaminate the groundwater.

## 2.2. Nitrate and Chemical Contamination

The contamination of groundwater by chemicals, especially nitrates from agricultural runoff, has emerged as a serious issue. Fertilizers and pesticides used in large-scale agricultural practices seep into the soil and leach into the groundwater.

- Nitrate Levels: In some areas, nitrate concentrations in groundwater exceeded 50 mg/L, which is above the safe drinking water limit established by health organizations (WHO recommends a maximum of 10 mg/L).

Agricultural Practices: The use of excessive fertilizers, coupled with inefficient irrigation techniques like flood irrigation, has contributed significantly to the contamination of groundwater resources.

- Health Concerns: The presence of nitrates in drinking water has been linked to blue baby syndrome (methemoglobinemia) in infants, as well as increased risks for cancer and gastrointestinal diseases among the local population.

### 3. Impact of Climate Change on Recharge and Evaporation

#### 3.1. Reduced Groundwater Recharge

The effects of climate change on the recharge of groundwater in the Western Desert are evident, with several key impacts observed:

- Decreased Precipitation: The study found that the annual rainfall in the Western Desert has decreased by up to 20-30% over the past few decades, which has reduced the natural recharge rate of aquifers.

- Reduced Surface Water Flow: Lower rainfall also leads to reduced surface water flow in ephemeral rivers and wadis, which further limits the ability of the desert to naturally recharge its groundwater reservoirs.

- Higher Evaporation: The increase in average temperatures, as a result of climate change, has led to higher evaporation rates from the soil and surface water bodies. This not only affects the water balance but also leads

to increased water losses through evaporation, further reducing the potential for recharge.

### 3.2. Impact on Recharge Rates

Groundwater recharge rates in the Western Desert are extremely low, with recharge from precipitation and surface runoff not matching the high rates of extraction. The region's aquifers, particularly the Nubian Aquifer, rely primarily on ancient recharge events that occurred thousands of years ago.

- **Recharge Gap:** The recharge-to-withdrawal ratio in many areas has become negative, with some reports suggesting that recharge is less than 1% of the amount being withdrawn.
- **Exacerbation by Climate Change:** Projections indicate that climate change will further reduce recharge rates, exacerbating the depletion of aquifers and leading to even greater water scarcity in the future.

## 4. Water Management Challenges and Inefficiencies

### 4.1. Irrigation Inefficiencies

The inefficiency of irrigation practices is another significant finding. Despite the introduction of modern irrigation technologies, many farmers in the Western Desert still rely on traditional flood irrigation, which leads to excessive water waste and high evaporation rates.

- **Irrigation Losses:** The study found that nearly 40-50% of the water used in traditional flood irrigation is lost through evaporation and runoff, compared to 20-30% in more efficient systems like drip irrigation.

- Technological Adoption: Although drip irrigation and other water-saving technologies are available, their adoption has been slow due to the high upfront costs and lack of training among local farmers.

## 4.2. Lack of Effective Policy and Regulation

The research also highlighted that current water management policies are insufficient to address the growing water crisis in the Western Desert. There is a lack of clear regulation and monitoring systems for groundwater extraction and quality control, leading to:

- Unregulated Extraction: Groundwater is often extracted without adequate monitoring of its long-term sustainability, leading to over-exploitation of resources.

- Policy Gaps: There is a need for stronger regulatory frameworks to enforce water conservation measures, promote the use of efficient irrigation systems, and protect water quality from contamination sources.

## 5. Potential Solutions and Future Prospects

### 5.1. Water Conservation Strategies

Several effective water conservation strategies have been identified through the study:

- Improved Irrigation Techniques: Promoting the use of drip irrigation and sprinkler systems can drastically reduce water losses in agriculture. Additionally, the introduction of water-efficient crops can further reduce water consumption.

- Desalination: The development of desalination plants using reverse osmosis or solar energy can provide an alternative water source, though the high cost and energy requirements remain challenges.

## 5.2. Policy Recommendations

The study calls for the implementation of stricter regulations and policies to ensure sustainable water use in the region, including

**Regulating Water Extraction:** The government must implement more stringent controls on groundwater extraction and introduce incentives for water-saving technologies.

**-Promoting Regional Cooperation:** Since the Nubian Sandstone Aquifer is shared by multiple countries, fostering regional cooperation and developing a joint management framework will help ensure equitable and sustainable use of this shared resource.

## 5.3. Research and Technological Innovations

Investments in research and technology are critical to understanding the long-term viability of groundwater resources in the Western Desert. Future research should focus on:

- Groundwater Modeling to predict future depletion scenarios and identify potential solutions.

- Water Quality Monitoring Systems to better track contamination levels and implement timely corrective measures.

In conclusion, the results of this study underscore the urgency of addressing the underground water problem in the Western Desert of Egypt. Groundwater depletion, contamination, and climate change are all compounding challenges that threaten the region's future water security.

Immediate action, including more efficient water management, sustainable extraction practices, and regional cooperation, is necessary to ensure the continued availability of this critical resource for agriculture, industry, and human consumption. By adopting innovative technologies, improving policy frameworks, and promoting sustainable practices, Egypt can mitigate the underground water crisis in the Western Desert and protect its vital water resources for future generations.

## **Recommendations:**

Recommendations for Addressing the Underground Water Problem in the Western Desert of Egypt

### **1. Sustainable Groundwater Management:**

- Implement strict regulations on groundwater extraction to prevent over-exploitation. Establish quotas and licensing systems for well drilling and water use.
- Develop and enforce policies that prioritize the use of renewable water resources over non-renewable fossil aquifers.

### **2. Promote Water-Efficient Technologies:**

- Encourage the adoption of modern irrigation techniques, such as drip and sprinkler systems, to reduce water wastage in agriculture.
- Invest in research and development of crops that require less water and are more suited to arid environments.

### **3. Enhance Data Collection and Monitoring:**

- Expand the use of remote sensing, Geographic Information Systems (GIS), and hydrological modeling to monitor groundwater levels and quality in real time.
- Establish a comprehensive database to track water extraction rates, recharge rates, and aquifer health.

#### **4. Invest in Alternative Water Sources:**

- Increase the use of desalination plants to provide freshwater for coastal and inland communities.
- Promote the reuse of treated wastewater for irrigation, industrial processes, and non-potable uses.

#### **5. Community Engagement and Awareness:**

- Educate local communities, farmers, and industries about the importance of sustainable water use and the risks of groundwater depletion.
- Involve stakeholders in decision-making processes to ensure that water management strategies are practical and widely accepted.

#### **6. Regional Cooperation:**

- Strengthen collaboration with neighboring countries (Libya, Sudan, and Chad) that share the Nubian Sandstone Aquifer System (NSAS) to develop a transboundary water management framework.
- Share data, technology, and best practices to ensure equitable and sustainable use of shared groundwater resources.

#### **7. Climate Change Adaptation:**

- Integrate climate change projections into water resource planning to anticipate future challenges and adapt accordingly.
- Develop drought contingency plans and invest in infrastructure to capture and store rainwater during rare precipitation events.

## **8. Economic Incentives and Policies:**

- Provide subsidies or financial incentives for farmers and industries to adopt water-saving technologies and practices.
- Implement pricing mechanisms that reflect the true cost of water to discourage wasteful use and encourage conservation.

## **9. Restoration of Ecosystems:**

- Rehabilitate degraded oases and springs by reducing groundwater extraction in critical areas and allowing natural recharge processes to recover.
- Protect and restore natural habitats that contribute to groundwater recharge, such as wetlands and vegetation cover.

## **10. Research and Innovation:**

- Support scientific research on groundwater recharge mechanisms, aquifer dynamics, and the impacts of climate change on water resources.
- Foster innovation in water treatment, desalination, and recycling technologies to improve water availability and quality.
- addressing the underground water problem in Egypt's Western Desert requires a holistic and multi-disciplinary

approach. By combining sustainable management practices, technological advancements, community involvement, and regional cooperation, it is possible to mitigate the current challenges and ensure the long-term availability of groundwater resources. These recommendations provide a roadmap for policymakers, researchers, and stakeholders to work together toward a water-secure future for the region.

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