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A General Study of the Water Resources Aquifer System Ghadames and Murzuq Basins - Libya

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ABSTRACT

The Murzuq and Ghadames Basins region, located in southwest Libya. Both basins are of high importance for hydrogeological systems, in North African Aquifer System Figure1. Bounded by Tibisti-Al Haruj to the east and Hoggar to the west, with extensions into Niger as the Djado Basin and Nafusa Uplift in the north. Both basins' surfaces are characterized by arid climatic conditions, experiencing extreme temperatures, minimal rainfall, and occasional torrential storms, underscoring the importance of their groundwater resources for sustainability.

Ghadames Basin is part of the Northwestern Sahara Aquifer System extends across Libya, Tunisia, and Algeria, highlighting its significance as a transboundary water resource.

The aquifer systems in the two basins encompass a variety of geological formations. The Murzuq Basin contains Upper, Middle, and Lower aquifers, ranging from Cambro-Ordovician to Cretaceous formations, with the Nubian and Post-Tassilian aquifers being extensively utilized for irrigation and domestic use. Similarly, the Ghadames Basin features the Senonian, Eocene limestone, and Turonian aquifers, which provide critical water supplies, but with varying mineralization and recharge dynamics influenced generally by geological and climatic factors. Hydrogeological assessments for both basins reveal significant variations in transmissivity, water table depth, and storage coefficients, showcasing ancient groundwater isotopic signatures indicative of minimal recent recharge.

Hydro-chemical analyses highlight diverse water qualities across both basins. In the Murzuq Basin, groundwater ranges from fresh to moderately saline, with Na-Cl and Mixed-HCO3 facies predominating, while the Ghadames Basin displays mineralization gradients linked to more recent recharge zones and the salinity challenges near areas like Oued Rhir and Ouargla. Both basins face significant challenges, including declining water levels, salinity intrusion, and contamination risks due to uncontrolled groundwater extraction and agricultural activities. In the Ghadames Basin, the impacts of large-scale projects like the Great Man-Made River further strain the non-renewable groundwater resources.

This study provides a regional comprehensive review of the hydrogeological and hydro-chemical characteristics of both Murzuq and Ghadames Basins, emphasizing the need for integrated, sustainable water management strategies and transboundary cooperation, particularly in the Ghadames Basin. Advanced monitoring, alternative water sources, and policy reforms are critical to mitigating over-extraction and ensuring the long-term viability of these vital water resources.

Keywords: Ghadames Basin · Murzuq Basin · Northwestern Sahara Aquifer System hydrogeology · groundwater · transboundary water resources · water salinity

Introduction and Regional Overview:

In general, the North African Aquifer Systems, particularly the North-Western Sahara Aquifer System, is vital for water supply in the arid regions of Libya, Algeria, and Tunisia. These aquifer systems play a major role in supporting agriculture, drinking water supplies, and other industrial activities across the region of these countries, despite the challenges posed by the non-renewable nature of the groundwater resources as generally say. In Libya, the Ghadames Basin is of a significant part and very crucial for providing water to the region. Understanding the hydrogeological and hydro-chemical characteristics both Basins is necessary for the sustainable management of these resources, especially considering the issues of groundwater extensive exploitation and transboundary water management is not well understood. The important issue shared resource among Libya, Tunisia, and Algeria, with key aquifer systems forming a critical part of the hydrological landscape.

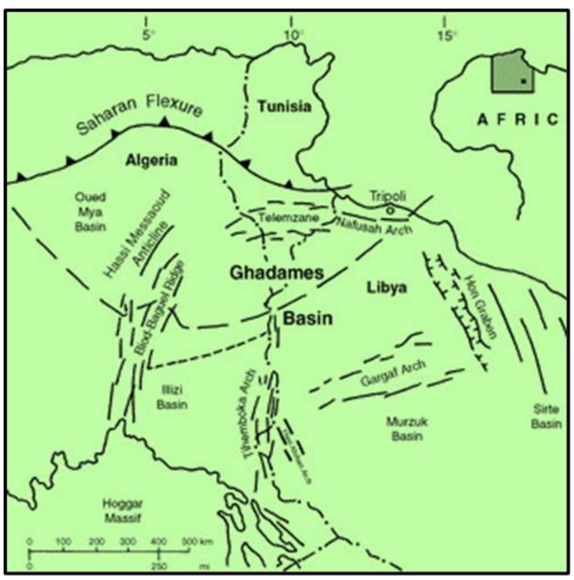

Figure 1. The Ghadames extends to Algeria and Tunisia in addition to Murzuq and Ilizi in North Africa. Emphasis will be given to the Libyan Basins.

Also, West Libya basins contains oil and gas fields, as major producers of hydrocarbons in Libya. The producing-bearing horizons of the two basins range in age from Cambro-Ordovician to Triassic. Reservoirs of Cambro-Ordovician, Silurian, Devonian and Peremo-Triassic age are major reservoirs producing horizons in the Ghadames and Murzuq Basins [1]. The Silurian Tanezuft shales (Llandovery) and the Upper Middle Devonian (Frasnian) are the main source rocks of hydrocarbons in the Ghadames and Murzuq Basins. The reservoir characteristics indicate that the hydrocarbons of the Ghadames basin have mainly accumulated in a combination of stratigraphic structural traps in areas close to Gargaf high, and in structural anticline traps in areas close to the center of the basin. In the Murzuq Basin, hydrocarbons are trapped mainly in structural faulted traps. The distribution of oil fields in the Ghadames and Murzuq Basins appears to be confined to a regional structural trend, which reflects the close relationship between tectonics, sedimentation, oil migration and accumulation.

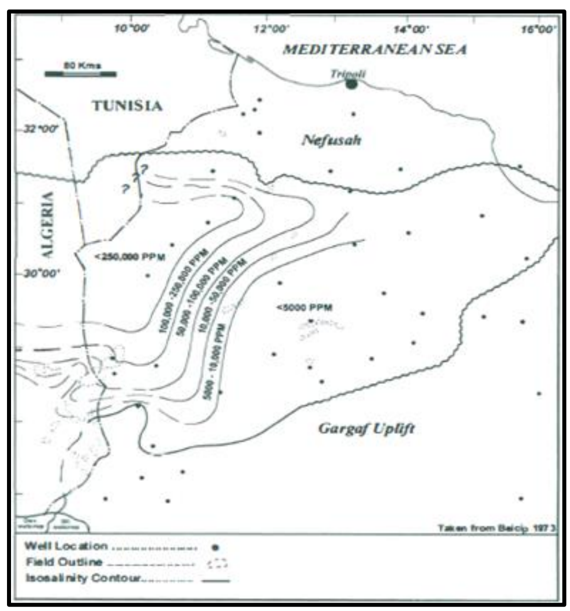

Figure 2. Iso-salinity map of the Early Devonian Tadrart Formation right above the Silurian along the Ardinan unconformity. After [2]

General Salinity distributions in Ghadames and Murzuq Basins:

Ghadames Basin:

The geological formations of the Ghadames Basin play a key role in shaping the aquifer systems ranging from Cambro-Ordovician to Cretaceous which provides the ability to store and transmit underground water. These formations went through many phases of strong periods of tectonism, erosion, redeposition and erosions of missing important sections leaving gaps of geological continuity of understand. The most important aquifers are the Triassic sandstone which date back to the Triassic and Jurassic periods, influence groundwater movement and water quality which used extensively domestically and by oil companies worked and working in the region of Ghadames Basin.

- **Triassic Formations**

The Triassic formations in the Ghadames Basin include a range of lithological units, such as clayey-sandy lower Trias, carbonated Trias, and saline Trias. These units vary in thickness and facies, with the saline Trias showing significant thickness in the northeastern part of the basin [3]. While these formations are not crucial for underground water flow, their geological properties influence regional hydrogeology.

- **Jurassic Formations**

The Lower and Middle Jurassic formations consist mainly of lagoon and marine layers, including salt, clays, anhydrites, and limestone. These layers contribute to the hydrogeological chemistry properties of the region, particularly in the Grand Erg of Ghadames Basin in Algeria and eastern portions of the Ghadames Basin in Libya. Their role in groundwater flow is significant, especially as these formations are permeable to varying degrees, depending on the presence of anhydrite and clay layers.

The Fresh and saline aquifers in Ghadames Basin is possibly influenced by recharge and infiltrates of fresh water from both regions of Algeria and Libya. In Libyan region of Northwest and Southeast of Ghadames Basin the influence of fresh water indicative Salinity decreases in southern areas of Ghadames Basin and north of Jabal Hassawna the water salinity is less than 5000 ppm continuing towards southeastern region of Gargaf Arch (Jabal Hassawna) and 100,000 ppm in the central region of the Basin to more than 200,000 ppm in the central region of the Basin. Salinity increases towards Algeria and Tunisia to more than 250,000 ppm.

The sudden increase of salinity towards the Northwest with no hydrostatic pressure possibly due to the Strike Slip faults rejuvenations and the conjugate faults associations or the presence of Tigi fault running more or less west east in Northern areas of Jabal Nafusa also the upper undifferentiated formations contain facies of high amounts of Salt composition such gypsum.

Most important is to highlight problems associated with water resources in the region of Ghadames Basin specially the decline of water in Kikla Formation productivity which can be identified by the technical and operational specifications of the selected wells already drilled in the region.

Also, the phenomenon observed in most areas of Ghadames Basin is the lack of hydrostatic pressure and productivity decline in the water supplies could be due to faults partially seep fresh water and communicate with the surface, but this problem identification needs to be investigated farther more with Isotopes. Also, the previous studies, field visits and laboratory tests coupled with statistical results should be incorporated in the study represent the important findings to overcome some of the occurring Nemours of problems and phenomenal concepts related to the observations. Other important underground waters constitute possibly fossil water layers shared between Algeria, Tunisia and Libya more likely related to impermeable basement which is important aquifers in the region of the three countries. This could be partially renewable through the numerous Strike Slip faults and conjugates associated with these faults in Ghadames Basin Libya, Algeria and Tunisia.

Northwestern part of Libya is the major water recharge supply pacifically, the groundwater in the Jeffares Plain region which has been under heavy use over decades by the rapidly by domestic, agriculture, industry missuses. The properties of water for specific application use by human consumption is considered vital for deciding the feasibility of the resource and its safeness for the public health and the environment. For human consumption, the chemical parameters of ground water should comply with the drinking water needs if these parameters exceeded the recommended values, the resource is considered unsafe and can be used for industries' important water supply. The present study is not investigating the hydro-chemical qualities of water in the northwestern region of Ghadames area for drinking water purposes and is not the main target but the study is concentrates on understand water quantities in Ghadames Basin area of Libya, Algeria and Tunisia to be mainly used for industrial purposes such as water injection in mature oil fields and exploiting oil/gas from shale source rocks present in the region.

Atshan Saddle area:

In Atshan saddle area the water reported in the Ordovician sandstone and the M'rar Formation of Carboniferous sequences which out crop and paved the area of Atshan with high values of Sulphate (SO4). This elements of high levels of sulphate could give the water a bitter or astringent taste which was reported by some French researchers. Sulphate (SO4) can occur naturally in most underground water of Atshan area makes this water unsuitable for human drinking, as well as animals but can be used in industrial purposes after analysis chemical analysis investigation. Also, unknown researches reported concentration of trace elements (Fe) and CO3, HCO3, Cl, SO4 and NO3 make water in Ghadames area of the northwestern Libya undrinkable. Conclusions concerning this issue are left for Future studies who should be able to classifies the waters according to its quantities and chemistry analysis in the northwestern Ghadames Libya in general. The area of Atshan Saddle considered one of the highly productive petroleum potential provinces with a long exploration history in Libya potential areas [1]. Most discoveries in the basin so far have been made in the Acacus Formation as primary target and Wan Kasa and Momenyiat formations. Small discoveries have been made in the Tahara and Mrar, Ras Hamia and upper Z sand of Tanezuft formations. The distribution of Tahara and Mra'r formations can be considered aquafers in some parts of both basins. The sandstone units of the Tahara and Mra'r formation could provide a good opportunity to explore for stratigraphic hydrocarbon traps. All of these sandstone reservoir intervals of the Paleozoic sandstone reservoirs are of low pressure and need to increase pressure by water injection in the aquafers at future stage of production from the existing oil fields. The different oil Pools in Atshan Saddle, Ghadames and Murzuq basins also in need for water source of low quality or saline water for future water injection to maintain the pressure of the different reservoirs at acceptable level for efficient production, a mechanism whose regional hydrodynamic implications can be compared with findings in surrounding basins [12]. The Tahara and Mra'r formations have not been sufficiently explored and studied yet, particularly in the central part of the basin, where the sandstone units in the Tahara and Mra'r formation could provide a good a good future opportunity to explore for stratigraphic traps.

Murzuq Basin:

The Murzuq Basin is located in the southwestern part of Libya, positioned within the desert climatic zone. This region is bordered by the Tibisti-Al Haruj Uplift to the east and the Hoggar Mountains to the west, extending into the Djado Basin in Niger. The basin is characterized by large sand dune fields, such as the Idhan Awbari and Idhan Murzuq Sand Seas, which dominate the landscape.

The stratigraphy of the Murzuq Basin reveals a succession of water-bearing formations ranging from the Cambro-Ordovician up to the Cretaceous periods. The basin has been classified into three major aquifer systems: the Upper, Middle, and Lower.

The underground water starts from the Lower Aquifer fresh water in the southern parts of the Murzuq basin, with levels excepted. In contrast, higher salinity levels are observed further north near Wadi Ashatti areas. The hydro-chemical facies exhibit a transition from CaNaMg-HCO3 in the south to Na-Cl in the north, influenced by groundwater flow directions.

The climate of Libya transitions significantly from north to south, influenced by the Mediterranean to the north and the Sahara Desert to the south. The Murzuq Basin, lying deep within the Sahara, experiences extremely arid conditions. Rainfall is exceedingly low, with most areas in the basin receiving less than 100 mm of rain annually. Higher rainfall is concentrated in the northern regions of Libya, such as Jabal Nafusah (250–300 mm annually) and Jabal Al Akhdar (550–600 mm annually), but these areas are far from the Murzuq Basin. These regional different highlights the vulnerability of western and southern water resources to changing environmental shifts [4].

The basin also faces high temperature variations, with winter lows recorded.

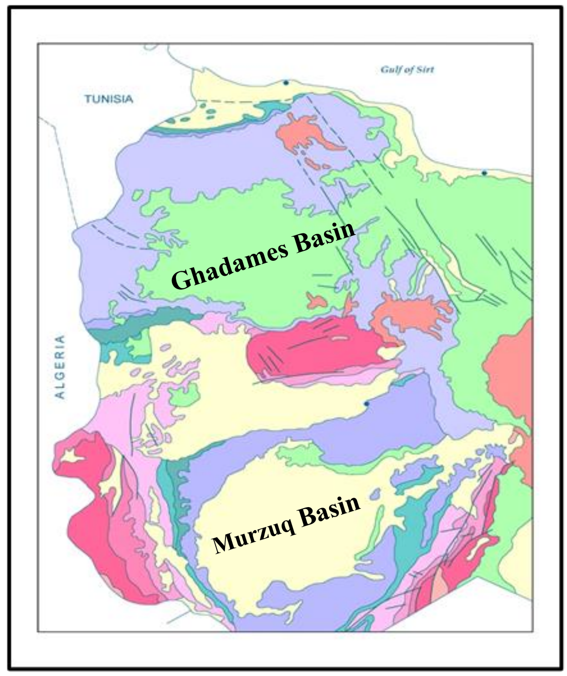

Figure 3. Location Map of Ghadames and Murzuq Basin surface geology. After [2].

These sporadic storms can cause flash floods but also impact on water resource availability.

The region's limited rainfall and high evaporation rates challenge both natural replenishment of aquifers and water management strategies.

The stratigraphy of the Murzuq Basin reveals a succession of water-bearing formations ranging from the Cambro-Ordovician to the Cretaceous periods. The basin has been classified into three major aquifer systems: the Upper, Middle, and Lower.

The Upper Aquifer System is represented by the Nubian and Post-Tassilian formations. The Nubian

Aquifer, composed of Jurassic to Lower Cretaceous sandstone, acts as an unconfined aquifer in many areas and is extensively utilized for irrigation and domestic purposes. Its transmissivity varying depends in area location and the type of lithology with water table depths varying between 6 meters to 40 meters. In some areas, clay layers within the Nubian Formation separate it from the Post-Tassilian Aquifer, which consists of sandstone, and gravel. The Post-Tassilian Aquifer is divided into shallow, intermediate, and deep zones, with varying discharge rates and static water levels, ranging from 5 to 800 meters in depth.

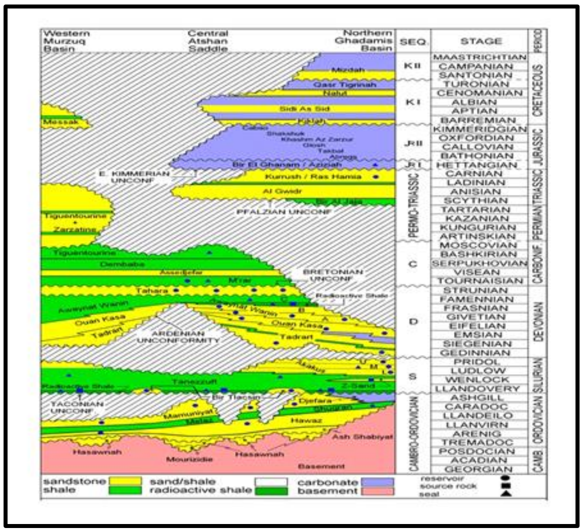

Figure 4. Stratigraphic column and Wheeler Diagram of Western Ghadames and Murzuq Basins.

The Middle Aquifer System encompasses Carboniferous limestone and Siluro-Devonian sandstone. While the Carboniferous Aquifer has limited productivity due to its restricted lateral extent and high salinity, the Siluro-Devonian Aquifer is more prominent, particularly along Wadi Ash Shati, where depths range from 20 meters to 200 meters.

The Lower Aquifer System is the primary deep-water source, comprising of Cambro-Ordovician quarzitic sandstone confined beneath thick clay layers. Artesian conditions prevail in the southwestern part of the basin, whereas unconfined conditions dominate the northeastern region.

The Murzuq Basin features a complex stratigraphy with formations ranging from the Cambro-Ordovician to the Cretaceous. The Jurassic formations of the Murzuq Basin include significant evaporitic sequences of sulfates and halites.

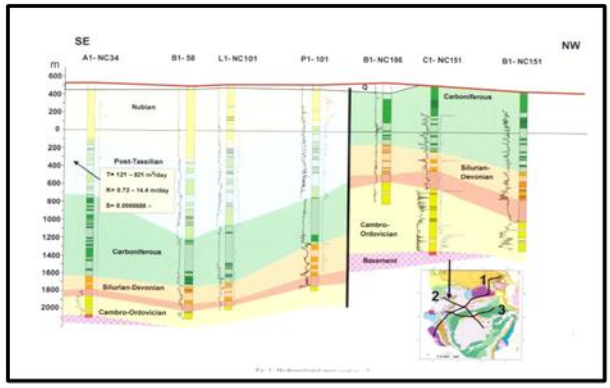

Figure 5. Hydrogeological Cross-section after [5]

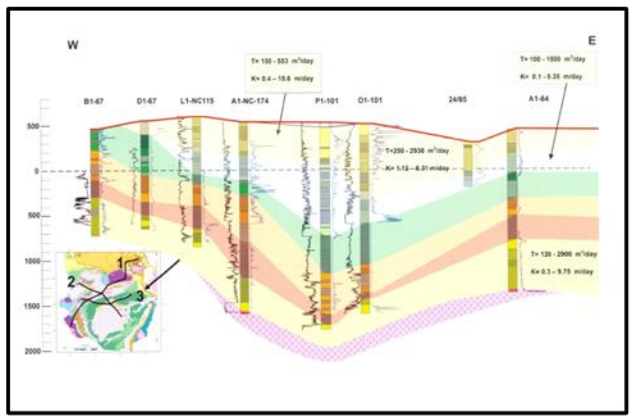

Figure 6. Hydrogeological Cross-section west east Murzuq basin after [5].

The porosity of the Nubian Sandstone in the southern and eastern Sahara is well-documented, hosting aquifers that have been tapped for groundwater resources, especially in arid regions like eastern Libya [6]. Furthermore, groundwater in these aquifers is also channeled through fracture zones in the rock, forming networks that enhance water storage and transport, playing a significant role in the localization and accessibility of groundwater [7]. These characteristics highlight the importance of the Murzuq Basin's aquifers in sustaining both industrial, agriculture and domestic water needs in a region prone to extreme aridity.

Water extraction in the Murzuq region is concentrated in depressions where the water table is close to the surface, such as in Wadi al-Ajal, Wadi Irawan, and Sabha. These areas, located near the northern limit of the Upper Aquifer's extension, show relatively lower transmissivity values compared to other regions in the basin.

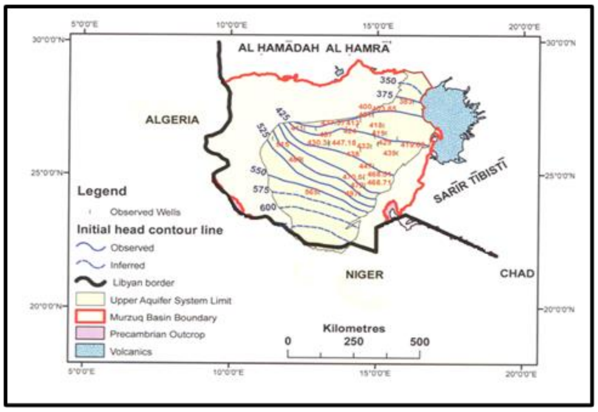

Figure 7. A map showing the general trend of groundwater movement towards the northeast of Murzuq Basin. After (El-Baruni & El-Futaisi, 2012)

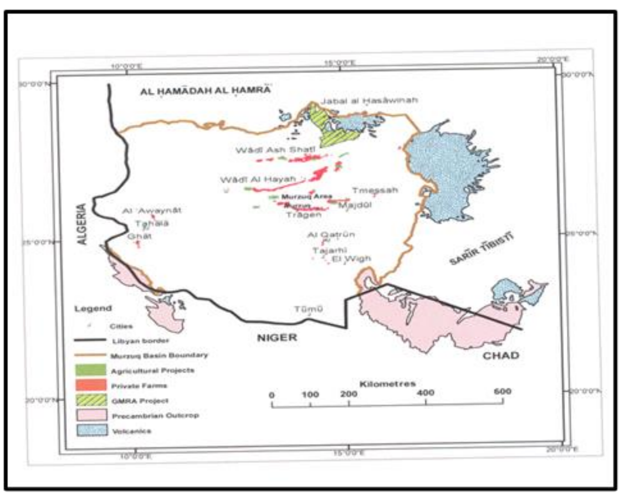

Figure 8. Groundwater extraction zones in Murzuq Basin after (El-Baruni & El-Futaisi, 2012)

Evidence suggests that groundwater in the Murzuq Basin may have connections to Quaternary paleo lakes that once existed in the region. [8] identify remnants of a large Quaternary lacustrine palaeo-lake within the Murzuq Basin. Furthermore, groundwater in the region may have originated from these mid-Quaternary lakes, which would provide valuable insight into the aquifer recharge mechanisms in this arid basin [8]. The Middle Aquifer generally contains moderately fresh water. The water's hydro-chemical facies are primarily Na-Cl, reflecting the influence of prolonged water-rock interactions. In regions near sabkahs, uncontrolled extraction has disrupted the natural equilibrium, causing saline water intrusion into previously freshwater-bearing formations. This phenomenon has been observed along a 300-kilometer belt on the northern edge of the Mesozoic aquifer system, particularly around areas of Wadi Irawan.

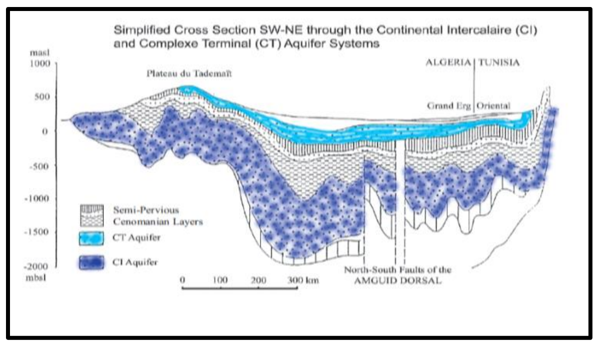

Figure 9. North–West to South–East cross section through the Northwest Sahara and Sahel Observatory, after Siegfried 2003 and Siegfried. 2004.

Hydrogeological Features of the Ghadames Basin

The Ghadames Basin extends across Libya, Algeria, and Tunisia, with key hydrogeological features that are influenced by both geological formations and climatic conditions. The NWSAS covers much of this region, and its groundwater serves as a critical resource for all three countries.

Recharge to the aquifers of the Ghadames Basin primarily occurs in areas to the south, particularly in Jabal Hasawnah (Gargaf Arch), which possibly feeds water to the Hamada area. The recharge flow extends towards the northern Ghadames area and southern Tunisia, without significant alteration in its natural course, except around extraction zones [9]. The dynamics flow possibly preserve the original distribution of water the only minor influence is the local variations occur in response to exploitation.

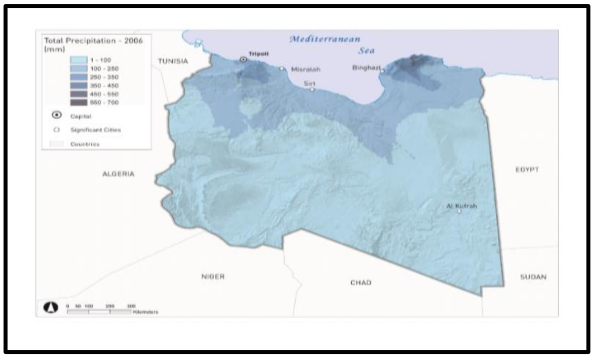

Figure 10: Annual average rainfall distribution of near coast of Libya. Unknown source

Figure 11. Water level decline from 1972-74-1999. Unknown source

One of the significant aquifers in the Ghadames region generally is the Senonian and Eocene limestone aquifer. In Algeria, this aquifer is exploited in the zone extending from Biskra in the north to Ouargla in the south, while in Tunisia, it is concentrated in the Nefzaoua region and the Ghadames Basin [9]. In Libya the Senonian and Eocene limestone aquifer are possibly extending to El Hamada El Hamra region, Jabal Nafusah, coastal areas of Al Khums and Tawurgha. The mineralization of waters in this aquifer varies, with regions showing low mineralization near recharge zones and high mineralization (over 5 g/L) near areas like Oued Rhir and Ouargla [9]. This variability in mineralization levels influences the suitability of water for various uses. The Turonian aquifer extends from Dahar in Tunisia to Jabal Nafusa in Libya. and Ghadames, is another important water source in the region. This aquifer is characterized by low stable isotope content which indicates minimal recent recharge. The isotopic signatures of the waters in this aquifer resemble those of waters found in the Continental Intercalaire (CI), suggesting that the waters are ancient, often exceeding 20,000 years in age [9].

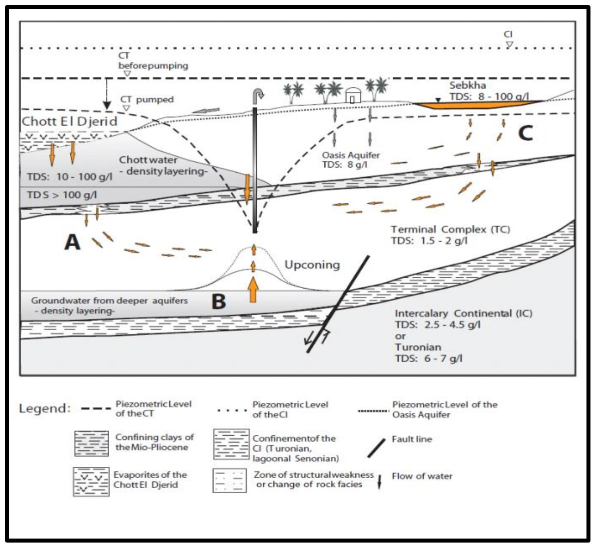

Figure 11. Conceptualization of the three differing salination processes. A: Infiltration of brine from Chott; B: Upcoming of IC/Turonian water; C: Pollution by agricultural drainage water After [10].

2. Geological Context of the Ghadames Basin

The geological formations of the Ghadames Basin play a key role in shaping the aquifer systems and their ability to store and transmit water. These formations, which date back to the Triassic and Jurassic periods, influence groundwater movement and water quality.

3.1. Triassic Formations

The Triassic formations in the Ghadames Basin include a range of lithological units, such as clayey-sandy lower Trias, carbonated Trias, and saline Trias.

These units vary in thickness and facies, with the saline Trias showing significant thickness in the northeastern part of the basin [3]. While these formations are not crucial for groundwater flow, their geological properties influence the regional hydrogeology.

3.2. Jurassic Formations

The Lower and Middle Jurassic formations consist mainly of lagoon and marine layers, including salts, clays, anhydrites, and limestone. These layers contribute to the hydrogeological properties of the region, particularly in the Grand Erg and eastern portions of the Ghadames Basin. Their role in groundwater flow is significant, especially as these formations are permeable to varying degrees, depending on the presence of anhydrite and clay layers.

3. Previous Studies and Hydrogeological Modeling

Several studies have contributed to the understanding of the Ghadames Basin's hydrogeological features.

These studies underscore the complexity of groundwater flow in the Ghadames Basin and the importance of integrated modeling efforts to ensure sustainable management of this crucial resource.

5. Water Exploitation and Policy Implications

The exploitation of groundwater in the Ghadames Basin, particularly through large-scale projects like the Great Man-Made River project, has raised concerns regarding the long-term sustainability of these resources. Given the shared nature of the aquifer systems, transboundary cooperation between Libya, Tunisia, and Algeria is crucial for managing these resources sustainably.

Sustainability and Resource Management

Current exploitation practices, such as those employed by the Great Man-Made River, are unsustainable in the long term due to the non-renewable nature of the groundwater. This calls for urgent policy reforms and strategies for the sustainable management of the aquifers.

Transboundary Cooperation

Since the Ghadames Basin spans multiple countries, effective water management requires cooperation between Libya, Tunisia, and Algeria. Studies like Siegfried [11] highlight the importance of shared management frameworks to address issues such as water salinity, equitable distribution, and long-term resource sustainability.

Continuity of the aquifers to the South with the Paleozoic

The Cambro-Ordovician of Jabal Hashanah appears as a large, quite fractured sandstone and quarzitic massif, outcropping and sub-outcropping to the north under a thin Palaeocene or Upper Cretaceous cover, over an area of more than 20 000 km2. Over a whole zone comprised between the 29th and the 30th parallel, the Lower Cretaceous aquifer (Kiklah) is in direct contact with the Cambro-Ordovician, thus ensuring a perfect hydraulic continuity between the two aquifer systems. This coupling of two systems presents two major and contradictory consequences:

– As the Cambro-Ordovician constitutes a large reservoir of unconfined aquifer, the Kiklah aquifer associated with it will benefit, even at a distance, from this considerable reserve;

– By contrast, as the zone of Jabal Hassawnah is the centre of a vast well field collecting the aquifer of the Cambro-Ordovician, intended to supply the western tributary of the Great (Manmade) River, the Kiklah aquifer will undergo directly the repercussions of the considerable abstractions (2.5 million m3 day) envisaged for the Cambro-Ordovician.

To the south-west, near the Algerian border, it is the Triassic detritic formations which advance further south. These formations are in contact with the impermeable aquifer and, therefore, there is in this zone no hydraulic connection with the Palaeozoic. In the eastern part of Hamada El Hamra, the aquifer reservoir of the Continental Intercalaire is not limited to the Kiklah series but is in continuity with the aquifer formations of the Triassic and the Jurassic. Further south (Jabal Hassawna), the hydraulic continuity between these formations and the Cambro-Ordovician is assumed to be the origin of supply of this aquifer.

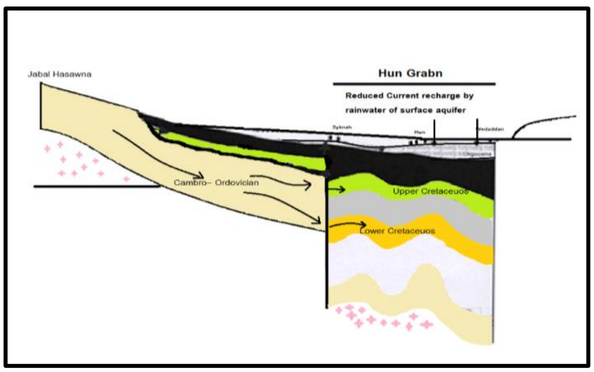

Fig 12. Role of the Hun graben in Al Jufrah zone which recharging by Jabal Hasawna, The NWSA Hydrogeology volume II

6. Challenges and Recommendations for Both Basins

The sustainability of the Murzuq Basin's water resources is contingent on addressing the challenges posed by over-extraction and contamination. Regulatory measures must be implemented to control groundwater use, particularly in areas near sabkahs. Adopting efficient irrigation techniques and encouraging the reuse of treated wastewater could alleviate pressure on the aquifers.

Advanced monitoring systems are essential for tracking changes in water levels and salinity. Policymakers must integrate these technologies into water management strategies to ensure the long-term viability of the basin's resources.

Conclusion

- Future research should focus on understanding the impacts of climate change on aquifer recharge.
- Evaluating alternative water sources such as desalination.
- Studies on the interaction between surface and groundwater systems could provide insights into mitigating contamination risks.
- The Ghadames Basin is crucial for providing water to the arid regions of Libya, Tunisia, and Algeria.
- Its hydrogeological and hydro-chemical characteristics are shaped by geological formations, recharge zones, and climatic factors.
- The basin's Senonian and Eocene limestone aquifers and Turonian aquifer provide essential resources, but the growing challenges of groundwater exploitation and water quality management require continued research and international cooperation.
- Effective aquifer modeling, policy development, and transboundary water management are critical for ensuring the sustainability of water resources in the region.
- Murzuq Basin plays a critical role in sustaining life and economic activities in southwest Libya. However, the increasing challenges of over-extraction, salinity, and contamination require immediate attention.
- Sustainable management practices and advanced monitoring techniques are vital to preserving this essential resource for future generations.

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