

Analytical hydrological study of the distribution of groundwater in Al-Qaim district and strategies for their management and sustainability

Abid Hammad Abid Al-Fahdawi

Aws Talak Mashaan Satam

Abi22h5003@uoanbar.edu.iq

Ed.aos.mishan@uonbar.edu.iq

College of Education for Humanities, University Of Anbar, Iraq

Abstract :

The research aims to distribute groundwater in the Al-Qaim district spatially and to identify the relational relationship between it and the geological structures, through a detailed geographical analysis of the depths of wells and the movement of groundwater in the reservoirs and reservoirs formed within them and analyzing their types, their feeding origin, the spatial distribution of wells and their levels, in addition to studying their depths and directions of water movement through them and the amount of their water discharge, which resulted in an integration of the spatial distribution, as four groundwater reservoirs are located within the study area with different depths and geographically distributed as follows: Umm Ardماه Formation (48-154) m, Ana (129-170) m, Euphrates (60-130) m, and Quaternary sediments (0.5-11) m. 43 wells were selected to cover the study area and the hydraulic analysis revealed differences in depth, level of decline, and productivity of the wells to reach a comprehensive assessment of the groundwater and the hydrological status of the wells, which resulted in A clear explanation of how to manage and sustain it.

Keywords: Groundwater Distribution, well Depths, Groundwater Movement, Hydraulic Analysis.

دراسة هيدروولوجية تحليلية لتوزيع المياه الجوفية في قضاء القائم واستراتيجيات ادارتها واستدامتها

ا.م.د. أوس طلك مشعان

م.م. عبد حماد عبد

Ed.aos.mishan@uonbar.edu.iq

Abi22h5003@uoanbar.edu.iq

جامعة الانبار / كلية التربية للعلوم الانسانية - قسم الجغرافية

المستخلص:

يهدف البحث إلى توزيع المياه الجوفية في قضاء القائم وتحليل العلاقة الارتباطية بين المياه والتكوينات الجيولوجية، ومن خلال التحليل الجغرافي لأعماق الآبار وحركة المياه الجوفية في الخزانات والتي تتناسب مع الاتجاه العام لانحدار المنطقة، وتحليل أنواعها ومصادر تغذيتها توزيع للآبار ومناسبتها، فضلاً عن دراسة أعماقها وكميات التصريف، الأمر الذي نتج عنه تكامل التوزيع المكاني، إذ تقع ضمن منطقة الدراسة أربعة خزانات جوفية موزعة عليها ابار المنطقة بأعماق مختلفة وموزعة جغرافياً على النحو الآتي: تكوين أم أرضمة (48-154) م، عنه (129-170) م، الفرات (60-130) م، ورواسب العصر الرباعي (0.5-11) م. تم انتخاب 43 بئراً لتغطية منطقة الدراسة، وأظهر التحليل الهيدروليكي وجود اختلاف في العمق وإنتاجية الآبار إذ كانت العلاقة طردية بين العمق والإنتاجية وتبين ذلك من خلال الدراسة الميدانية إذ سجل انه كلما زادت اعماق الابار ارتفعت الانتاجية، الأمر الذي نتج عنه تقييم شامل للمياه الجوفية والحالة الهيدرولوجية للآبار وأفضل السبل لإدارة هذه الموارد بشكل مستدام.

الكلمات المفتاحية: توزيع المياه الجوفية، أعماق الآبار، حركة المياه الجوفية، التحليل الهيدروليكي.

1. Introduction:

The scarcity of surface water resources poses a significant challenge, particularly in arid and semi-arid regions such as the study area. These regions are characterized by low precipitation rates and high evaporation, which exacerbate the imbalance between water supply and demand. According to (Gleick, 1993), arid and semi-arid zones account for approximately 41% of the Earth's terrestrial surface and face acute shortages of renewable water resources. This issue is further compounded by population growth, which increases water demand for domestic, agricultural, and industrial uses. For instance, (Alley, Reilly, & Franke, 1999) reported that water demand in such regions is projected to double by 2050 due to agricultural expansion and urbanization.

Additionally, human activities, including military operations and land use changes, have significantly impacted water availability. (Foster & Chilton, 2003) found that unsustainable land use practices contribute to groundwater quality degradation, with nitrate and pesticide contamination increasing

by up to 30% in areas with intensive human activities. These pressures necessitate a deeper understanding of the groundwater system to mitigate over-exploitation and degradation.

Groundwater resources play a vital role in sustaining communities in water-scarce regions, acting as a buffer against surface water shortages. A thorough analysis of aquifers' hydraulic characteristics is critical for effective groundwater management. This includes identifying recharge sources, which, as noted by (Scanlon, Healy, & Cook, 2006), can range from 2% to 10% of annual precipitation in arid areas. Furthermore, understanding the spatial distribution, depth, flow directions, and discharge rates of groundwater is essential to ensure sustainable utilization (Healy & Cook, 2002).

The urgency of the water crisis has highlighted the need for alternative solutions to bridge the water supply gap. One viable approach is the extraction of stored groundwater, which (Gleick, 1993) emphasized as a short-term remedy that requires careful management to prevent aquifer depletion. However, such strategies must be guided by comprehensive studies to balance

extraction rates with natural recharge processes and future demands.

2. Problem and Hypothesis

The spatial distribution of wells in Al-Qaim District is influenced by various factors, including depth and production capacity. This study seeks to examine whether hydrogeological factors have contributed to the distribution of wells, the flow of water, and the decline in groundwater levels in the region. It hypothesizes that an interconnected set of factors, including variations in well depths, quantities and quality of water extraction, and production capacity, alongside the steady demand for water, have shaped the characteristics and quality of groundwater layers. Additionally, natural factors such as the topographic and geological characteristics of the area have contributed to the ongoing decline in groundwater levels, compounded by excessive exploitation and insufficient natural recharge.

3. Importance of the Study

Understanding the spatial distribution of groundwater wells and their associated factors is critical for sustainable water management. This study

highlights the need to identify the most significant groundwater reservoirs in the study area, assess groundwater levels, and analyze their depths, recharge methods, and sustainability. Moreover, it focuses on determining the costs of groundwater extraction and investment to ensure long-term use. Groundwater well productivity serves as a vital measure of a reservoir's ability to supply water, as it reflects storage capacity, drainage periods, and subsidence values. Effective drainage processes depend on various factors, including withdrawal rates, which should not exceed recharge rates to prevent depletion. Proper management also reduces sediment accumulation in wells, mitigating groundwater pollution and safeguarding ecosystems. By evaluating these elements, the study aims to provide insights into sustainable practices for groundwater usage and preservation in Al-Qaim District.

4. The geographical location of the study area and the wells that were examined:

The study area is located in the western part of Iraq and Anbar Governorate, defined by longitudes

5. Geographical Distribution of Groundwater Reservoirs

Groundwater reservoirs in the study area exhibit diverse geological and hydrogeological characteristics, each with distinct properties affecting water availability and extraction.

5.1. Umm Er Radhuma Formation

This reservoir is located in the southern border areas near the Rutba district and extends westward to the Iraqi-Syrian border. The sedimentary nature of the reservoir is not conducive to water infiltration as it is composed of dolomite, shale, and clay, which are impermeable formations. However, the presence of fractures, cracks, and cavities in the rock formations has facilitated the recharge of the reservoir from surface runoff and regional waters, which has contributed to increasing its capacity. The formation's thickness varies from 120 to 180 meters, while its depth ranges between 48 and 154 meters, making water extraction easier. The permeability ranges from 0.1 to 21.1 m³/day, and the transmissivity from 2 to 1550 m³/day.

5.2. The Groundwater Reservoir in Anah Formation

The discoveries of this formation are evident in the lands from which the waters of the Haditha reservoir have receded. Limestone constitutes the majority of the rocks of this formation, as the fractures contributed to the formation of the rock body in the geological formation of Ana, which resulted in high values of the reservoir's water charge, as its thickness ranges between (129 and 170 m), while the permeability of the rocks recorded values ranging between (0.2 to 2.2 m²/day), and the permeability of the water recorded values ranging between (2 to 430 m²/day), due to the large size of the reservoir formed within the Ana formation and the high water storage capacity, which made it a major source of water in the region.

5.3. Euphrates Formation

The Euphrates Formation outcrops on the right side of the Euphrates River and along the river's course within the study area. The formation's thickness ranges between 60 and 130 meters. The rocks in this formation are limestone, composed of limestone breccia, conglomerates, and chalky limestone.

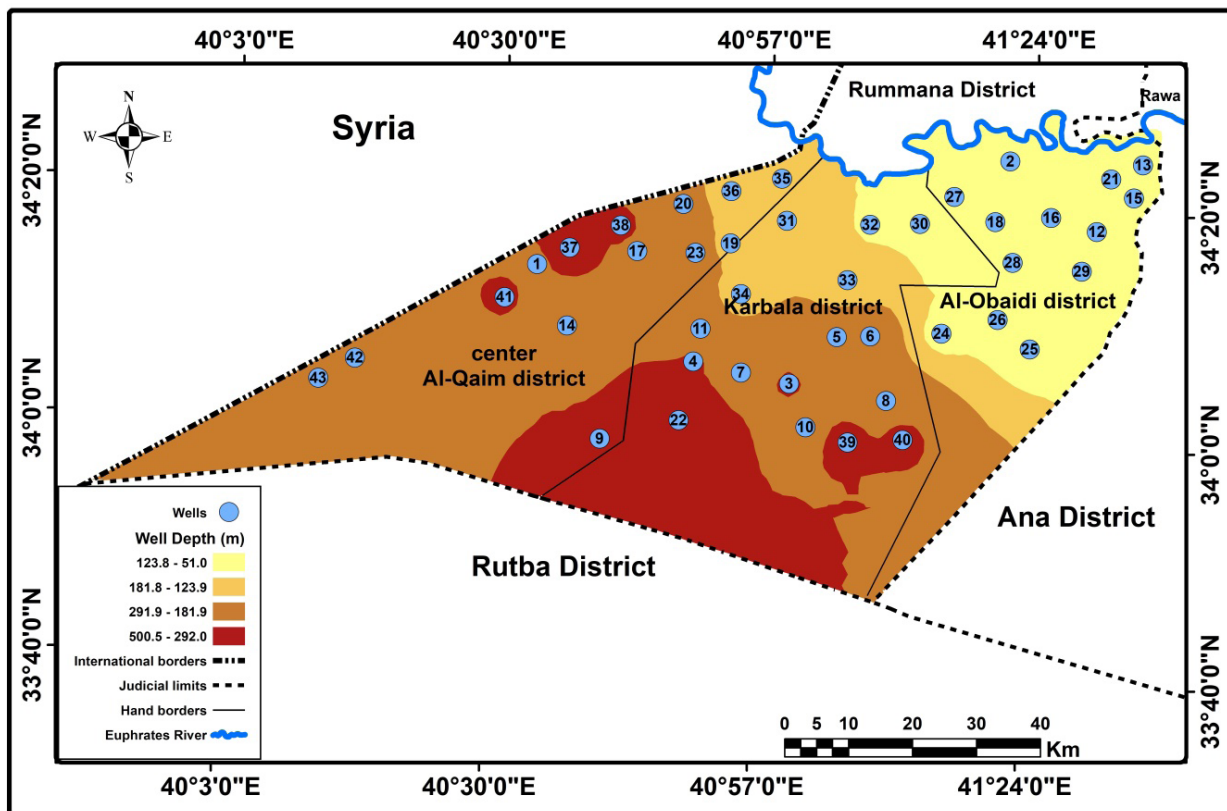
The presence of fractures and cavities within the region's rocks has facilitated vertical and horizontal water movement through them. The maximum thickness of the reservoir is 130 meters in the northeastern parts, decreasing as we move southwest of the Euphrates River, reaching 60 meters. Transmissivity values range between 3 and 1750 m²/day, while permeability varies between 0.2 and 29.5 m²/day.

5.4. Quaternary Deposits

The thickness of these deposits

ranges between 0.5 and 11 meters. The transmissivity values of the reservoir range between 4 and 1370 m²/day, and permeability ranges from 0.5 to 22.3 m²/day. The discharge of wells tapping into the Quaternary deposits varies under the influence of two factors: the characteristics of the rocks and their proximity to the feeding surface waters. Therefore, the efficiency of the wells and the continuity of their flow depend on the proximity of the recharge sources.

Map (2) The depth of drilling wells in Al-Qaim district



Reference: by researcher by ArcGis 10.8.

6. Geographic Distribution of Wells in the Study Area

To provide a detailed explanation of the spatial distribution and depths of the wells, the selected samples in the Al-Qaim district and its associated sub-districts were divided as shown on map (1), as follows:

6.1. Al-Qaim District Center

A total of 14 wells were identified in the district center, with drilling depths ranging between 350 meters for well No. 37 near the Iraqi-Syrian border and 120 meters for well No. 35 near the center of Al-Qaim district. The depths of these wells gradually vary from south to north and northeast, due to the topography of the area and the slope of its layers in this direction. These wells are located within the elevation range of 144-437 meters above sea level as in map (2).

6.2. Wells in Al-Karabila Sub-district:

The depths of the groundwater wells in this sub-district varied, reflecting the area's topography and slope. There were about 16 observed samples within this sub-district, as shown on map (1). The deepest well in the area reached about 500.5 meters in well No.

22, while the shallowest depth recorded was 120 meters in well No. 34.

6.3. Wells in Al-Ubaidi Sub-district:

The number of wells in Al-Ubaidi sub-district reached about 13, with variations in their distribution and depths. The maximum depth recorded was 100 meters in well No. 25, while the minimum depth was 51 meters in well No. 2. Most of the wells drilled in the area are recent and were intended for irrigation of agricultural lands in response to the recent reduction in water allocations to various districts and sub-districts of the governorate. The shallow depth of the wells is attributed to the low topography of the area, as well as the presence of the Anah reservoir and the Quaternary aquifer, which are close to the surface and have mixed waters due to direct seepage from the Euphrates River.

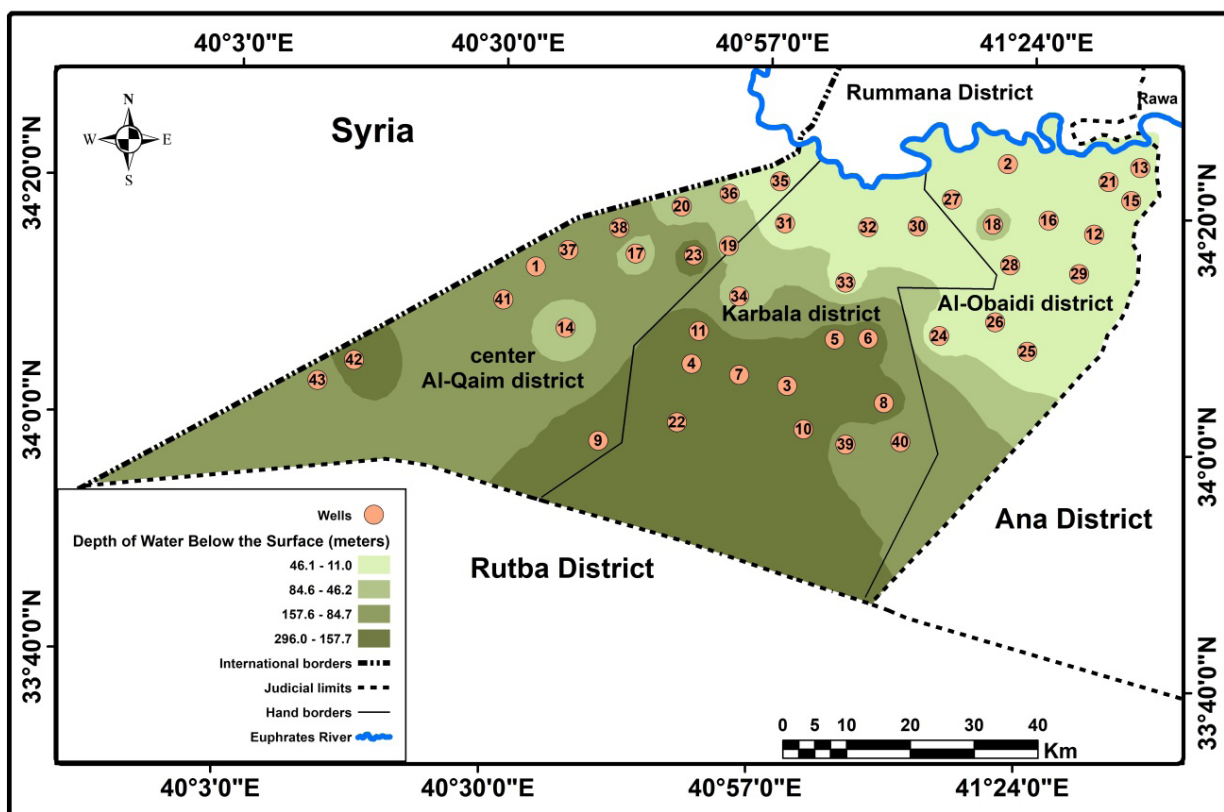
7. Depths of Groundwater Below the Surface

The analysis of the data in map (3) reveals that there is a variation in groundwater depths within the Al-Qaim district and its associated sub-districts. Moreover, this groundwater

depth varies even within the same district. This variation is due to several factors, including the area's topographic conditions, sources of recharge, and the inclination of the water-bearing layers from the south and west towards the north and northeast, as well as the

impact of extraction activities. The map (1) shows that groundwater depths are variable. To analyze the well depths in the Al-Qaim district and its sub-districts more accurately, they were categorized as follows:

Map 3: Groundwater depths from the ground surface (m) in Al-Qaim District.



Reference: by researcher by ArcGis 10.8.

7.1. Wells in the Al-Qaim District Center

The variation in the depths of groundwater in the center of the Al-Qaim district resulted in recording the

lowest depth of 16 meters in Well 35. The reason for this decrease is the feeding from the valleys of Faheeda and Hameeda in the study area, while the highest depth was recorded in Well 23

at 232.7 meters. This is due to the variation in the topographical elevations of the area when compared to the shallow wells in the center of the Al-Qaim district, in addition to the high costs of drilling wells, which prompted the population to drill wells with relatively shallow depths that suit the needs of the population to grow certain crops as needed.

7.2. Wells in Al-Karabila Sub-district

The shallowest well depth in Al-Karabila was recorded at 11 meters in well No. 30, making it the shallowest well in the study area. This shallow depth is due to the recharge provided by Wadi Al-Qaim, one of the largest

valleys flowing into the Euphrates River within the Al-Karabila sub-district. The deepest well in the area, No. 22, reached a depth of 296 meters. This depth is due to the area's higher topography and the weak recharge from the valleys in the region. Generally, well depths tend to decrease as one moves from the south toward the northern areas near the Euphrates River, where seasonal valleys increase recharge and reduce depths. Additionally, the shallower depths in the northern parts are due to the lower topographic slope, which varies from 437 meters in the south to 144 meters near the Euphrates River in the north.



Reference: by researcher (Wadi Zala stream).

7.3. Wells in Al-Ubaidi Sub-district

The wells in Al-Ubaidi recorded the lowest average depths in the study area, with the shallowest depth being 19 meters in well No. 2. This shallow depth is due to the presence of Wadi Al-Saqra and several small valleys in the area that flow into the Euphrates River, as well as the lateral recharge from the Euphrates River, which increases the recharge of the groundwater reservoirs. The greatest depth recorded was 62 meters in well No. 18. This depth is attributed to the area's topography, with the slope varying from 320 meters in the well area to 144 meters near the Euphrates River.

ues for these levels. The lowest value, 194 meters, was recorded in well No. 23, located in the southern part of the district. This is due to the presence of a network of valleys that intersect the area, including Wadi Al-Humaydiyah and some tributaries feeding Wadi Al-Manai, which have contributed to recharging the reservoirs. The highest value for moving levels, 234.9 meters, was recorded in well No. 41. This is attributed to the limited recharge through the valley network and the area's high elevation, as well as human factors, such as the increased water extraction from wells, especially those far from the Euphrates River.

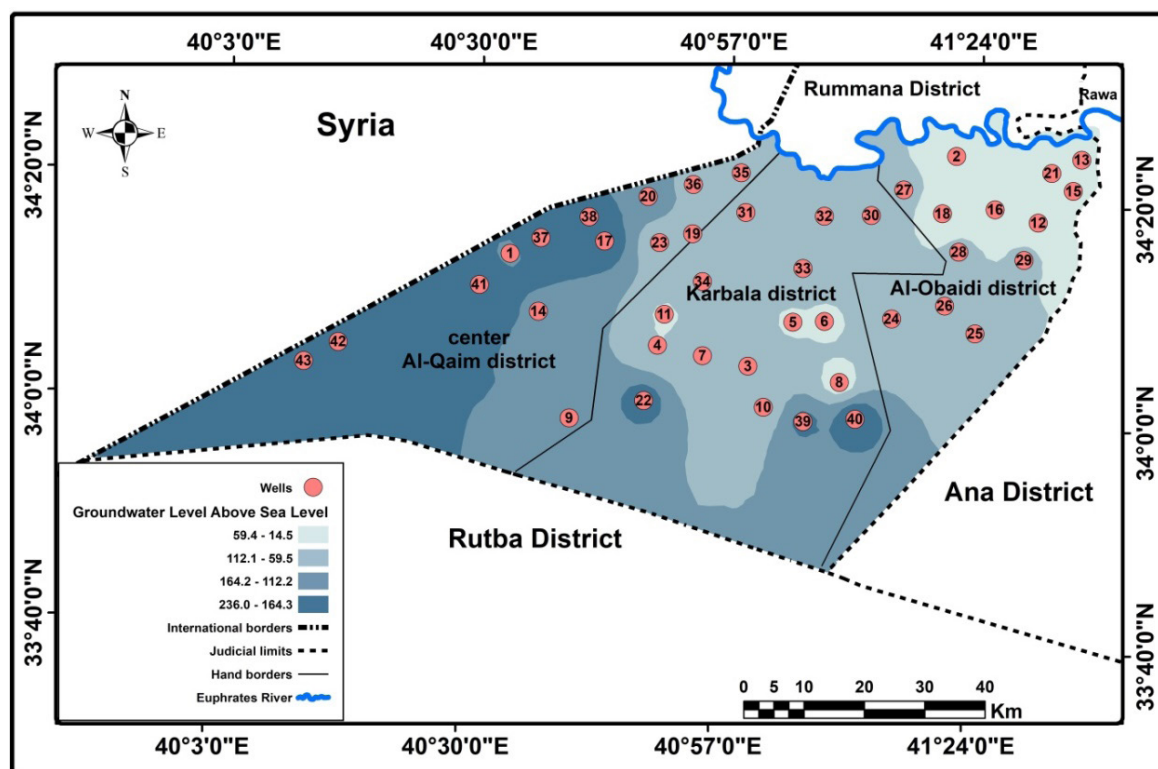
8. Groundwater Levels in Al-Qaim District

The analysis of the data in map (4) indicates that there is a variation in the groundwater levels from one area to another. This will be explained in detail as follows:

8.1. Moving Groundwater Levels in the Al-Qaim District Center:

The moving groundwater levels within the Al-Qaim district center vary, with the wells showing high val-

Map (4): Groundwater levels (m) relative to the ground surface and sea level for the Qaim District



Reference: by researcher by ArcGis 10.8.

8.2. Moving Groundwater Levels in the Al-Karabla District

The moving groundwater levels in Al-Karabla District fluctuate from one location to another. The lowest level recorded was 198.2 meters in well No. 6, located in the southern part of the district. This is due to the well's proximity to the Al-Manai valley, which enhances groundwater recharge. The highest level recorded was 240 meters in well No. 39, attributed to the high-

er topography and relatively lower recharge volume.

8.3. Moving Groundwater Levels in the Al-Ubaidi District

Al-Ubaidi District shows more consistent groundwater levels. The lowest level recorded was 24 meters in well No. 28, located in the southern part of the district. This is due to the well being situated between Al-Qa'im and Al-Jarrah valleys, which increases groundwater recharge. The highest moving level

recorded was 60 meters in well No. 25, likely due to the area's topography, as the region is elevated and located in a watershed area, particularly the Anah syncline, which influences recharge.

9. Drawdown Levels

9.1. Drawdown Levels for Wells in Al-Qa'im District Center

The drawdown levels in Al-Qa'im District Center wells vary. The lowest drawdown from the static level recorded was 2.2 meters in well No. 7. This is due to its location within cavernous formations (Nafaila and Zahra) and within the recharge zone of the Al-Rutka valley. The highest drawdown from the static level recorded was 97 meters in well No. 10, due to weak surface recharge, especially in an area with elevated topography. Additionally, the well depth does not reach the deeper, water-rich layers benefiting from regional recharge. Continuous extraction using high-capacity pumps has also contributed to the significant drawdown.

9.2. Drawdown Levels for Wells in Al-Karabla District

The wells in Al-Karabla District exhibit significant variation in drawdown

levels. The lowest drawdown from the static level recorded was 0.3 meters in well No. 4, while the highest drawdown from the static level recorded was 98 meters in well No. 16. The low drawdown in well No. 4 is due to the substantial recharge from the Al-Manai valley. The high drawdown in well No. 16 is attributed to weak surface recharge, increased extraction volumes, and the use of water for agricultural purposes, as shown in Table 1.

9.3. Drawdown Levels for Wells in Al-Ubaidi District

The wells in Al-Ubaidi District recorded the lowest drawdown rates compared to the rest of the study area. The lowest drawdown recorded was 2 meters in well No. 12, due to continuous recharge from the Euphrates River through the Anah formation. The highest drawdown recorded was 40 meters in well No. 9, attributed to weak surface recharge in the aquifer due to the well's location in a watershed area, which reduces percolation, as well as continuous extraction and high pump capacity exceeding the rate of natural recharge.

Table (1) Drop Level (m) for Wells in the Qaim District.

Landing	Well No.	Well	Landing	Well No.	Well	Landing	Well No.	Well
3.4	5896	1	31.6	7901	1	14	5924	1
10	5863	2	1.7	5886	2	14.2	5905	2
3	5689	3	14	5867	3	27.7	5940	3
51.2	5892	4	0.3	5866	4	32.6	5867	4
35	5903	5	21	5847	5	11.5	5899	5
47.5	5902	6	2	5702	6	13	5941	6
2.2	5860	7	11	5972	7	9.3	5862	7
63.5	Saadi Saleh Ahmed	8	5	5894	8	19.5	Sulaiman Mehr Abdul	8
83.3	Makar Al-Theeb Village	9	22	5940	9	40	Mari Hamoud Khalaf	9
97	Al-Bufahd Village	10	56.5	5893	10	12.7	Mahmoud Hilal	10
95	Al-Baharon Village	11	55.5	Khalid Youssef	11	7.1	Ahmed Saleh Hamad	11
55	Border Guard	12	38	Nouri Obeid Jabir	12	2	Baha Taes Hamoud	12
76	Border Guard	13	36	Khalif Ali Kedi	13	7.7	Hassan Talal Hamoud	13
The level of the decline in the waters of Al-Qaim District (47.9)			58	Aboud Muham-mad Ali	14	The level of the water level in Al-Ubaidi district (16.3)		
			3	Saleh Ahmed Kedi	15			
			98	Saadallah Hamoud Ali	16			
			72	Akash Village	17			
			The level of the water level in Al-Karabila district is (30.9)					

10. Groundwater Movement

10.1 Groundwater Movement in the Center of Al-Qa'im District:

Groundwater in the center of Al-Qa'im District moves in line with the general slope of the area, from the west and southwest towards the east and northeast. The discharge of the upper aquifers flows towards the Euphrates River, while the aquifers located below the river's flow level discharge towards the Al-Ubur district, outside the study area boundaries, due to the general inclination of the layers in this direction, as shown on the map.

10.2 Groundwater Movement in Al-Karabla District

The movement of groundwater in Al-Karabla District mirrors that of surface water, moving from areas of high hydraulic pressure to areas of low pressure. The flow moves from the south towards the north and northeast, with the Euphrates River serving as a discharge area for surface and near-surface groundwater in this region.

10.3 Groundwater Movement in Al-Ubaidi District

The groundwater movement was recorded in line with the general ten-

dency of the rock layers in Al-Ubaidi district, as it recorded a dynamic movement from the south towards the north towards the Euphrates River Valley, in addition to recording an opposite movement of groundwater, as groundwater moved from the center of the district towards the south and southwest, due to the presence of a water divider represented by a fold, which resulted in the movement of water in a linear manner in line with the direction of the slope of the fold, while the opposite side of the fold recorded the movement of groundwater towards the north and northwest, to form water reservoirs that contributed to the formation of a local movement of groundwater within the region, and is a positive factor that contributed to the accumulation of water and the formation of a large groundwater basin.

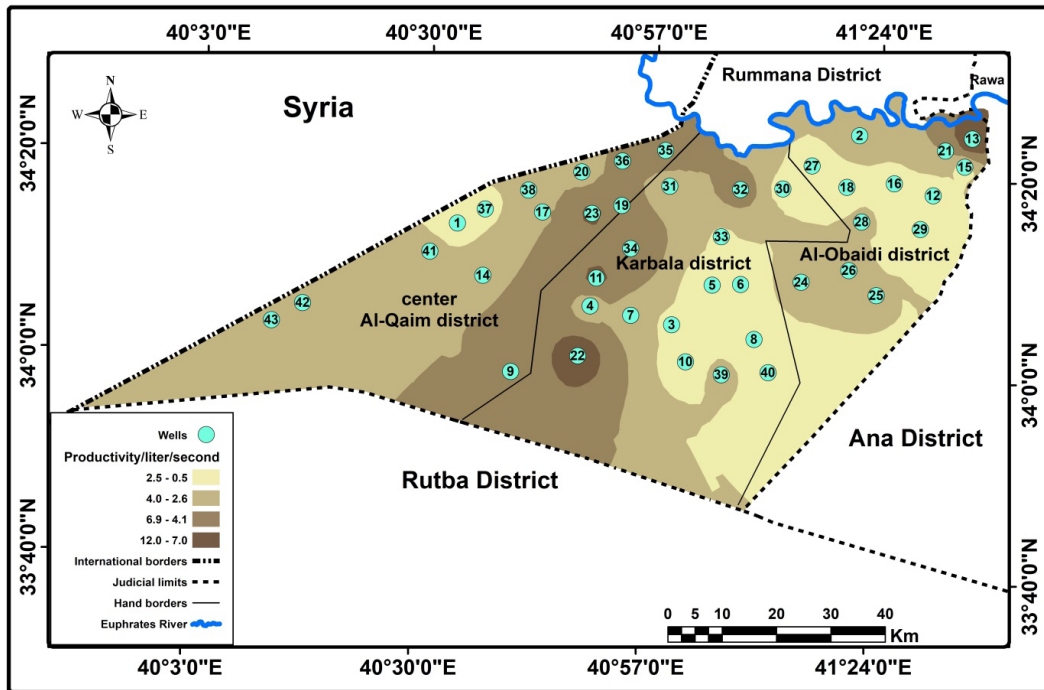
11. Well Water Discharge

The production capacity of the groundwater reservoir is a measure of the groundwater layer's capacity and its ability to provide water, store it, drain it, and flow levels. The drainage process is affected by a set of factors that contribute to determining the amount of water

that can be extracted for use in various needs. Regular drainage of wells in the study area reduces the chances of depletion, as withdrawal rates do not usually exceed the natural water charging rates of the wells. Balanced drainage also contributes to reducing the chances of sediment accumulation in them. Continuous water extraction improves the quality of the water and renews it regularly. The natural characteristics of the region are a crucial element in the productivity of the wells, and this is represented in the quality of the soil and rocks that form groundwater reservoirs. The topography of the region and its geological formation, which includes voids and rock fractures that are close to seasonal valleys in the direct recharge of the wells, in addition to the direction of the layered slope of the rocks that determined the movement of groundwater and contributed to its recharge from areas that are in direct contact with the drainage area, which helped in determining the areas of the depths of the wells; Since productivity is relatively low, this requires increasing the depth of wells to increase productivity. Based on this, it is possible to determine the appropriate locations

for drilling wells, and determine the most appropriate pumping rates based on the type of pump and a set of scientific standards that are compatible with the characteristics of the well and the type of use. Therefore, well water discharge rates are essential for managing water resources to ensure their sustainability and provide for the needs of the population.

Map 5: Production Capacity of Wells in Al-Qa'im District in Liters/Second



Reference: by researcher by ArcGis 10.8.

The field study measured the discharge of a group of wells, and the data for each well was recorded using traditional methods (*). By analyzing the data in map (5), a large variation appears in the productivity of each well compared to the other. The reason is

a set of factors, the most important of which are the geological formations and their ability to transfer water, the size of the underground reservoirs and their depths, as well as the number of pumping hours from each well, which determines the appropriate pump size.



Reference: by the researcher (2024).

Specific Capacity

Specific capacity represents the rate of well productivity per unit of draw-down in groundwater level and is expressed in units of (liters/second/ meter). The specific capacity of wells can be used to determine their economic feasibility, which reflects the potential for sustainable groundwater use within limits that prevent depletion and ensure environmental sustainability. It is calculated using the following formula:

$$\text{Specific Capacity} = (\text{Average Well Productivity (L/s)} / (\text{Average Draw-down (m)}))$$

From analyzing the data in Table (2), and after applying the formula to the wells in the study area, it was found that the highest value was recorded in Al-Ubaidi District at (0.2 L/s), followed by Al-Karabla District at (0.1 L/s), and then Al-Qa'im District at (0.06 L/s). All values were low. The higher specific

capacity values for wells in Al-Ubaidi District compared to other areas are due to surface recharge through seasonal valleys descending from areas of piezometric pressure and continuous recharge from the Euphrates River into the aquifers through openings and fractures, as well as water acquired by aquifers through infiltration from rainfall. Additionally, most of the wells in Al-Ubaidi District draw water from multiple aquifers, including the Umm Er Radhuma Formation, which increases their values. On the other hand, the lower specific capacity values in the other areas are due to the dominance of the Umm Er Radhuma Formation, characterized by low transmissivity and permeability rates, as well as the presence of the upper reaches of water-courses, which have a minimal impact on water recharge, especially in the southern parts of the study area.

Table 2. The specific capacity rate (liters/second/m) of the wells of Al-Qaim District

Specifications	Specific Capacity	Rate of Land-ing Surface (m)	Rate of Productivity L/s	Wells
low	0.06	47.9	3.2	Al-Qaim District Center Wells
low	0.1	30.9	3.3	Al-Karabila District Wells
Low	0.2	16.3	3.1	Al-Ubaidi District Wells

13. Conclusions

1. There are four groundwater aquifers in the study area: Umm Er Radhuma, Anah Formation, Euphrates Formation, and Quaternary deposits. These aquifers vary in thickness, with the first aquifer ranging from 120 to 180 meters, the second from 129 to 170 meters, the third from 60 to 130 meters, and the fourth from 0.5 to 11 meters.

2. A total of 43 wells were studied, distributed across all areas of the study site based on their names, geographical coordinates, elevations above sea level, depths, and drilling dates.

3. The geographical distribution of the wells shows that there are 14 wells in the center of Al-Qaim district, with depths ranging from 120 to 350 meters. In Al-Karabla subdistrict, there are 16 wells, with an average depth ranging from 120 to 500.5 meters. Meanwhile, the Al-Ubaidi subdistrict has 13 wells, with depths varying between 51 and 100 meters.

4. Groundwater levels in the study area varied, with the lowest recorded level being 194 meters in the center of Al-Qaim district. The levels in

Al-Karabla subdistrict showed considerable variation, with the lowest level at 198.2 meters. The levels in Al-Ubaidi district were more consistent, with the lowest recorded level at 24 meters.

5. Regarding the specific capacity of the wells, after applying the equation to the wells in the study area, the highest value was recorded in Al-Ubaidi subdistrict at 0.2 liters per second, followed by Al-Karabla subdistrict at 0.1 liters per second, and then Al-Qaim district at 0.06 liters per second. All values were found to be low.

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