Identification of encroachments on water resources (groundwater) in the areas of fish concentration ponds in Daquq district / Kirkuk governorate using geospatial techniques

Nawal Kamal Khursheed[1], Wael F.A. Alshamary[2], Noorjan Essmat Noori[2] and Mohammed Mahdi Khurshid[3]

[1]Department of Artificial Intelligence , College of Engineering Computer and Artificial Intelligence in Kirkuk, Northern Technical University, Kirkuk, Iraq.

[2] Department of Soil Science and Water Resources, College of Agriculture, University of Kirkuk, Kirkuk, Iraq.

[3]Directorate of Maintenance of Irrigation and Drainage Projects, Kirkuk, Ministry of Water Resources, Kirkuk, Iraq.

Email: nawalkamal@ntu.edu.iq

waelfahmi@uokirkuk.edu.iq, essmat.noorjan@uokirkuk.edu.iq, mohamedmahdikh491@gmail.com

Abstract:

Groundwater has become a crucial element for achieving water security in Iraq, especially in areas with limited surface water or severe climate fluctuations. Particularly in regions with limited surface water or extreme weather swings. With the depletion of water supplies, especially in semi-arid and agricultural areas, the prominent rise in artificially created water bodies (fish lakes) and the drilling of uncontrolled groundwater wells have raised concerns about the sustainability of the groundwater resource and hydrological balance of the region, particularly in Kirkuk Governorate's Daquq district. Thus, the study was performed using geospatial technologies for 2016, 2019, and 2024, to figure out water resources (groundwater) violations in points of areas where fish lakes are distributed in places around Daquq district/Kirkuk Governorate.

The study found that in 2016, there were about 334 ponds with an area of about 4,558075 m³ and total water volume of about 6837112.5 m³ Approximately 8,901,096.69 m³ was calculated based on the measured depth of evaporation (1.363 m) — a high water loss for 2024 with the total water volume reaching almost 19,967,513m³ as related to its presence in over 486 ponds evaluating an overall area by 13 311675 m2. The maximum loss of water during the study period was estimated at 16,546,412.51 m³ which is equivalent to an evaporation depth of 1.234 m, and August presented higher values in the months evaluated (0.320 m water depth), while April showed lower evaporation values in relation to other months (evaporation depth of around 0.1756 m estimated loss of about 800397.97). The highest evaporation values at 0.4626 m occurred in July of the year 2016. This resulted in a significant loss of approximately 2,108,565.50 m³ of water. There was a gradual decrease in vegetation cover from 4444.72 hectares in the year 2016 to 2840.44 hectares in the years between 2019. In 2024, this number then fell again to relative increase with continues follow upto3782 hectares. Fish lakes exhibited a quick increase 1823.23 hectare in 2016, 2930.25 hectare in (2019) and5342.67hectares (2024), suggesting a significant pattern of pond development during this period. For spatial dominance the industrial fish ponds for fish farming in 2025 ended up second in area at 5,324.67 dunams down from and total reduction to1100.82 hectares (71171 acres) (Table 2). This group is particularly significant for the present study as it exclusively relies on extracting groundwater through underground wells which emits considerable hydraulic pressure on water reservoirs. Worked on the vegetation cover that existed in an area of research with a limited area of 3682 dunams where their covered ranked third of all cover indicators. This drop highlights the rarity of water supplies. While surface water bodies ranked last,

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covering an area of 748.89 dunams. This low percentage reflects the inadequacy of the surface hydrographic network and the very low water discharges caused by recurrent droughts and excessive withdrawals.
The data also show however a very typical use of deep wells almost 138.2150 meters deep, adding direct pressure on the aquifer itself, endangering its future viability, particularly with irregularity of rainfall and high summer temperatures. In light of that reality, the problem seems more one of a continuing pattern of excessive water use beyond the area's capacity to sustain than just an increase in economic activity. The use of these means, so that regulation starts with an "eye that sees", before a "hand that punishes" -- remote sensing and geographic information systems for basin and change monitoring; the creation of a complete geographic database to activate control over well drilling and water extraction via strict regulation and more precise consumption measurement (meters).

Keywords: Water encroachments, Fish ponds, Groundwater, Daquq district
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Introduction:

Water is one of the most important natural resources to save life and ecosystems on the earth planet.. Water resources have been affected in terms of quality and quantity, they have become rarer and dangerous since the second half of the twentieth century [1], as a result of decreasing water reaching Iraq from the Tigris and Euphrates rivers, which has decreased significantly compared to previous years. This is due to the construction of many dams within Turkish state, which represent the source upstream of the Tigris and Euphrates rivers, thus reduces the amount flowing to Iraq. Because of increasing water demand as a result of the expansion of population populations and several other activities, in addition to climate change in the region in general, this leads to an increase in the evaporation rates of surface water [2].

The groundwater is one of the most important natural resources that human beings depend on in their daily life, especially in areas that suffer from a shortage of surface water or severe climatic fluctuations. Groundwater has become a fundamental pillar of water security due to the increasing challenges posed by climatic variations and the decline in water inflows from external sources, especially in arable and semi-arid regions.

The Iraqi government has taken steps to conserve groundwater resources, In light of the increasing demand for water, the extensive expansion of irrigation, industrial and economic activities, as well as the impacts of climate change—particularly in arid and semi-arid regions, Therefore, groundwater is a resource that cannot be neglected or depleted in an unplanned manner, given its vital importance for sustaining life in Iraq. Globally, it represents the third major source of water after rainfall and surface water [3]. Groundwater comes from the infiltration of rain through the earth, which is then naturally stored in aquifers. It becomes one of the significant sources of fresh water The growing population and expanding agriculture and industry, notably plants in the form of artificial fish ponds have resulted in a greater reliance on groundwater and its considerable depletion. As a result, groundwater has been over-exploited, which brought out serious environmental problems like land subsidence and saltwater intrusion [3]. The over-extraction without strict scientific studies is one of the main causes affecting such an important resource as groundwater [4].

Over the last couple of years, Dawhaq district in Kirkuk province has seen a rise in activity in the construction of fake lakes or what is known in local parlance as (fish ponds). They are then usually created by the illegal digging of groundwater wells for recreation or business. Such ungoverned growth in groundwater of extraction also raises various questions in respect to legitimacy, sustainability and environmental erosions concerning the reserve balance.

Remote sensing and Geographic Information Systems (GIS) technologies have contributed to the advancement of groundwater studies by identifying potential water-bearing zones and efficiently monitoring spatial and temporal changes [5]. The district of Daquq in Kirkuk governorate is among the areas that have experienced significant expansion in the establishment of fish ponds, largely dependent on the irregular drilling of groundwater wellsSuch expansion has put a stress and endanger the aquifers sustainability.

This study aims to employ geospatial techniques to monitor encroachments on groundwater in areas of fish lake expansion within the district of Daquq, and to support the sustainable management and conservation of water resources for future generations.

Objectives of the study

This study aims to detect the locations of fish lake construction using satellite imagery and to measure their areas, as well as to identify their actual presence on the ground. The study also seeks to produce maps that assist the specialized authorities in the Ministry of Water Resources in making rapid decisions to address these issues with minimal time and effort. In doing so, it contributes to reducing groundwater waste, which may otherwise evaporate or deeply infiltrate from these basins. Furthermore, the study involves creating digital maps to estimate the amount of water consumed by these basins and providing practical recommendations to mitigate groundwater depletion in the region.

Materials and methods

Geospatial techniques (GIS & Remote Sensing) were used to study the encroachments on groundwater in Daquq district.

The research steps included:

1. A spectra-radiometer was used to collect 13 samples from fish ponds across the study area. These samples were analyzed to obtain spectral signatures, enabling the identification of fish ponds for each year within the study area. The device was employed to measure spectral reflectance values of water across wavelengths ranging from 350 to 2500 nanometers within the electromagnetic spectrum. In addition, a GPS device was used to determine the coordinates of wells, with depths ranging between 12 and 150 meters.
2. Satellite imagery (Sentinel-2 and Landsat 8) was analyzed to detect changes in water bodies and land cover.
3. Spectral indices (NDVI, NDWI, NDBI, and NDMI) were applied to analyze environmental and hydrological changes

Tools and devices used in fieldwork

1- ArcGIS software to perform spatial analysis, create and map the distribution of depths and service range for wells.

2- ERDAS Imagine software for processing satellite images and extracting spectral properties.

3- Microsoft Excel software for organizing data and creating tables and charts.

4- Microsoft Word for preparing manuscript, formatting texts, and tables [8].

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Figure 1: SPECTRO-RADIOMETER

Description of the study area

Astronomical Location

The study area is located between two longitudes (20” 07′ 44° and 19” 33′ 44°) east, between latitudes of (13" 40′ 34° and 03" 27′ 35°) north. The total area of the study region is approximately 8,918 hectares. The Daquq district lies within the semi-arid zone of northern Iraq.

Table 1, Coordinates of the samples for the study area

Latitude (N)	Longitude (E)	m
34.986417	44.493334	**1**
35.000851	44.521639	**2**
35.017182	44.542676	**3**
35.048806	44.524111	**4**
35.079978	44.508069	**5**
35.119010	44.483372	**6**
35.157350	44.454462	**7**
35.182645	44.420092	**8**
35.162507	44.388228	**9**
35.145569	44.366355	**10**
35.104584	44.354043	**11**
35.048267	44.409563	**12**
35.018876	44.455197	**13**

3.2 Geographical location

Kirkuk city centre occupies the north, Salah al-Din province is to the south, Tuz Khurmatu district to east and southern suburbs in western Kirkuk. This is an area that offers enormous geo-

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geographic centrality with relevance to agriculture and development

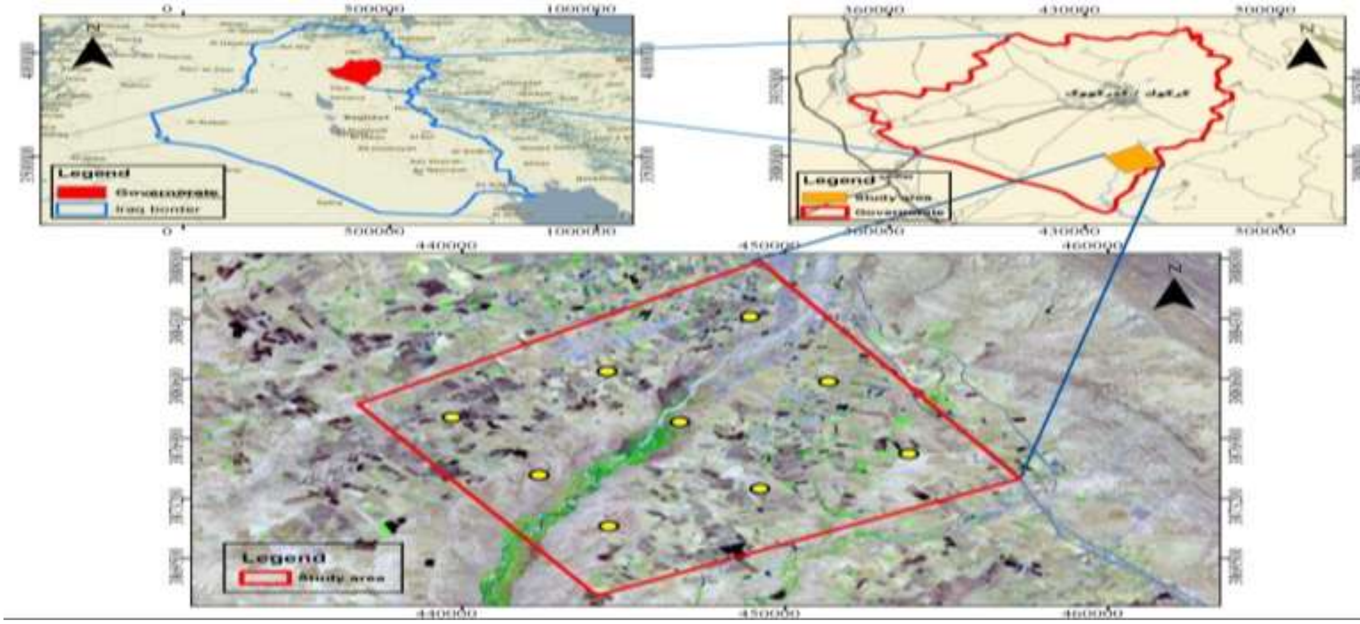

Figure 2: Map of the study area

Natural properties (surface and geology)

The study area has relatively flat to gentle undulating terrain over alluvial plains with uncomplicated geological structures. This makes it usable for multiple agricultural activities.

Table (2) and figure (3): spatial distribution of the geological formations for the study area, and it can be seen that the third time occupied the largest proportion and area in most parts of the study area, where its size reached 1106.8 km2. Such formations are composed of heterogeneous alluvial rocks such as limestone, marl and clay, which exhibit different degrees of permeability and openness to cracking with time [9], implying the possibility of being water reservoirs for groundwater but they are more susceptible to depletion under dynamic pumping rates.

On the other hand, Quaternary deposits cover an area of approximately 154.1 km², mostly concentrated in low-lying regions and along valleys and floodplains. These deposits consisted of relatively recent unconsolidated materials such as gravel, sand, and silt, that are characterized by high permeability and a greater capability to recharge groundwater aquifers. Nevertheless, due to their proximity to the surface and the ease of accessing groundwater within them, they are more susceptible to pollution and overuse.

This variation in geological formations contributes to explaining the spatial differences in groundwater distribution and the spread of fish ponds within Daquq district. Activities related to well drilling and lake construction tend to concentrate in areas of Quaternary deposits, as they provide easier excavation conditions and higher groundwater levels, thereby increasing the likelihood of water-related encroachments compared to areas of Tertiary deposits.

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Table (2) Geological Formations of the Daquq Region

Formations	Area (km2)
Quaternary (Q)	1106.8
Tertiary (T)	154.1

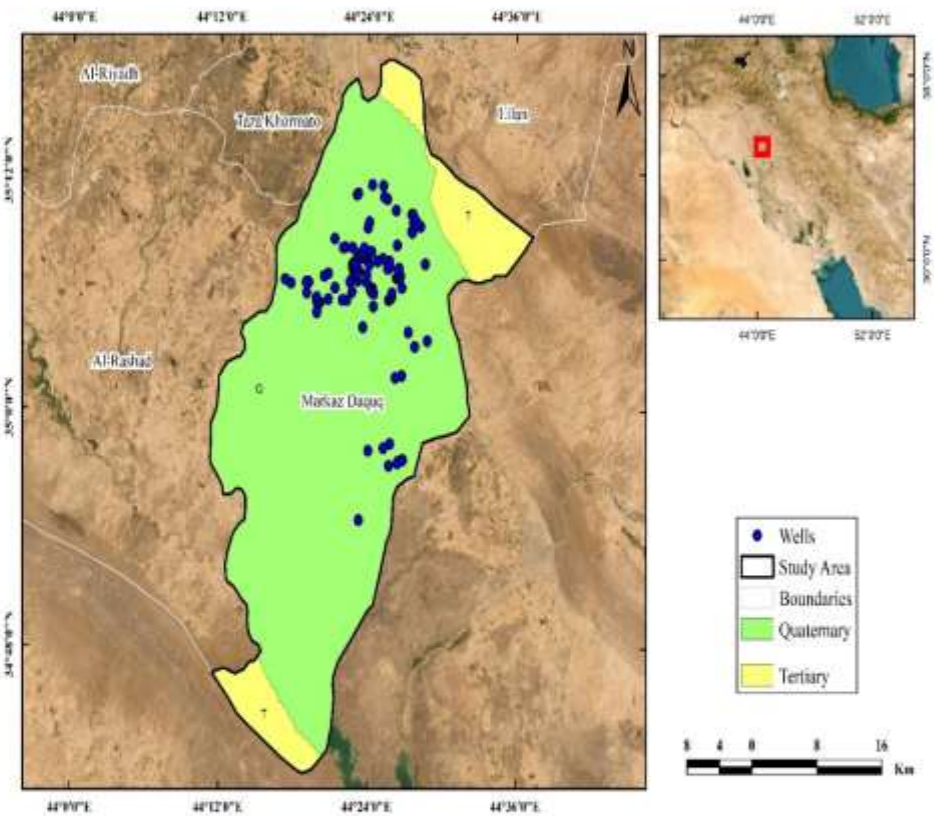

Figure (3): Map of the geological formations of the study area in Daquq district - Kirkuk Governorate

Climatic properties and water resources: The study area is Dominated by a semi-arid climate, characterized by high summer temperatures and low rainfall concentrated in the winter season. In recent years, the increasing reliance on groundwater as the main source of water has been driven by the noticeable decline in the levels of the Tigris and Euphrates rivers, resulting from both climatic changes and human factors [10].

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As shown in Figure 4, the study area exhibits marked monthly variations in rainfall amounts (mm) across the years 2016, 2019, and 2024. Precipitation is predominantly concentrated in the winter and early spring months (January–March), while during the summer season it declines sharply, approaching negligible levels between June and September

The data revealed that the highest rainfall quantities recorded in March 2016. As the values exceeded 40 mm wall, whereas the other winter months (January and February) relatively revealed medium quantities. The noticeable increase in rainfall quantities recorded at January, 2019 with gradual decrease in the other months of rainy season. Contrary, the year 2024 revealed relatively different pattern, as the rainfall concentrated obviously in March and November with clear decrease in other winter months.

This variation among years reflects the irregularity of the rainfall regime and the influence of climatic fluctuations on the region, which directly affect groundwater recharge rates [11]. Due to prolonged summer droughts and fluctuations in annual rainfall amounts, dependence on groundwater has increased to meet agricultural demands and activities associated with fish ponds

These results reveal that the continuity and discontinuity of rainfall doesn't provide sufficient stable natural feed for groundwater, which partially explain the expansion in wells excavation and increasing the construction of fish ponds in study area. It is of great importance to merge climatic data with geospatial analysis to understand the dynamics of exhaustion of groundwater to fix sustainable strategies of water resources management.

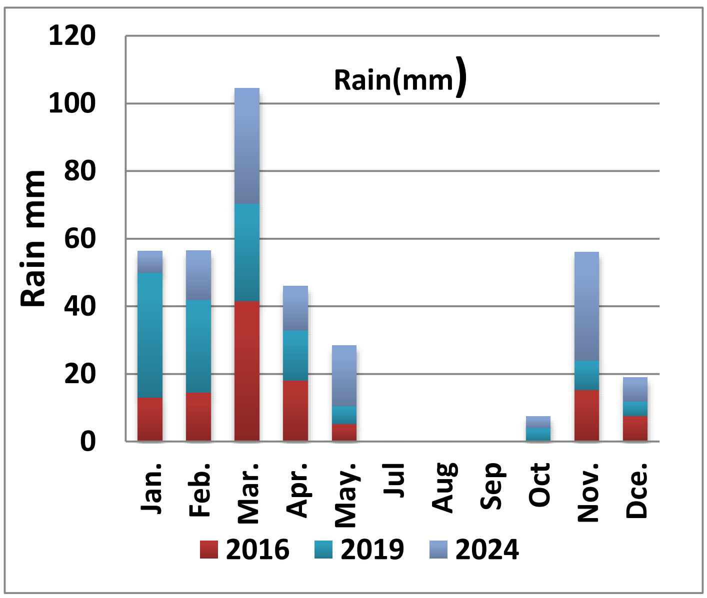

Figure (4): Monthly changes in rainfall amounts in Daquq district - Kirkuk Governorate

Soil and agricultural activities

The dominated soils in study area are silty and clayey suitable for cultivation, which has contributed to the expansion of agricultural activities, particularly cereal cultivation as well as the construction of fish farming ponds.

Human characteristics and environmental pressures:

Daquq district is dominated by rural character. Many residents in Daquq depend on agriculture and fish farming as a main source for income. The population is often distributed near water sources and groundwater wells, which has increased pressure on the aquifer as a result of the intensive use of water for

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irrigation and domestic uses, and which has contributed to the emergence of environmental challenges related to the sustainability and quality of water resources in the study area.

Spatial Analysis of the Distribution of Well Depths in the Study Area:

Table 3 and Figure 5 illustrate the distribution of well depths in Daquq district, Kirkuk province. The analysis shows that about 874.14 km² of the study area have wells with hydraulic heads varying from 138.2 to 145 m depth. Following them are wells with a depth of 145 to 150 m spread over an area of 395.7 km². The pattern implies that most deep groundwater wells are located within this zone, which is consistent the region depending on deep aquifer to meet water demand.

By contrast, 0.03 km² are occupied by shallow wells with depths varying between 42.7 and 95.3 m respectively.

This indicates the restricted use of shallow groundwater and also highlights their potential vulnerability to contamination [12]. Whereas the intermediate-depth wells, ranging between 95.3–124.8 m and 124.8–138.2 m, occupy relatively smaller areas compared to the deep wells. This distribution reflects a clear pattern of groundwater exploitation, with emphasis placed on deeper aquifer layers to benefit from larger storage capacities and to mitigate the impacts of climatic variability on water supplies.

This deep well distribution reflects the close relationship between groundwater sustainability and the risks of encroachments, as the heavy dependence on deep wells can, in the long term, lead to a decline in groundwater levels and a depletion of water storage if sustainable management mechanisms are not followed. Spatial analysis also shows that areas of deep well distribution often coincide with areas experiencing high density of fish farm construction, increasing the likelihood of additional water pressure and underscoring the need for close monitoring of these areas [13].

Table (3): The area of the wells' depths in study area

Depth (m)	Area (km2)
42,7 - 95,3	0.03
95,3 - 124,8	0.12
124,8 - 138.2	0.66
138,2 - 145	874.14
145 - 150	395.7

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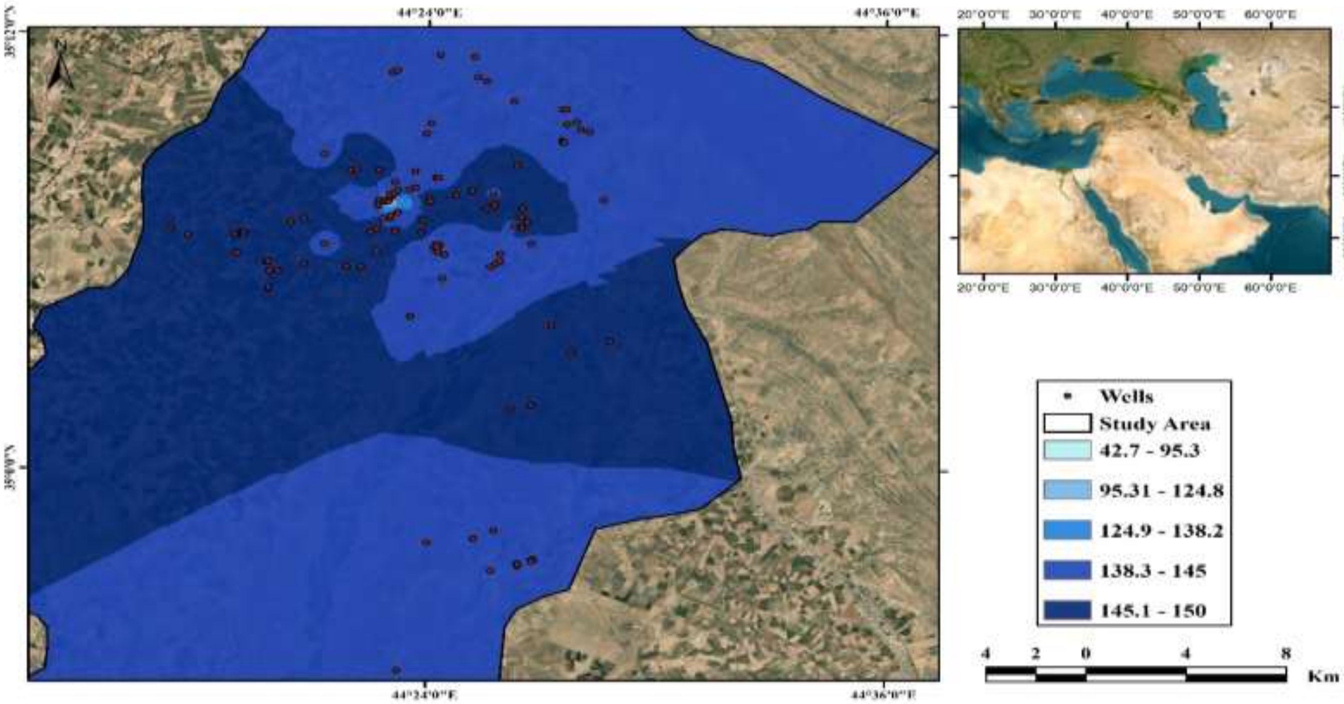

Figure 5 shows the distribution of wells depths in Daquq-Kirkuk province

Range of areas served by wells in the study area:

Table 4 and Figure 6 illustrate the distribution of service zones dependent on groundwater wells in Daquq district within the study area. The largest serviced area falls within the 1000 m zone, covering about 87.50 km², followed by the 1500 m zone with approximately 80.80 km², and the 2000 m zone covering around 71.20 km². In contrast, the nearest service zone of 500 m accounts for 53.70 km².

This spatial distribution reflects the prevailing pattern of dependence on groundwater to meet water demands. The majority of service areas are concentrated within the intermediate zones (1000–1500 m), indicating a relatively balanced distribution of well locations in relation to the serviced areas. In contrast, regions within the larger radius (2000 m) exhibit a lower level of service, underscoring the need to improve spatial planning of well locations to achieve greater efficiency in covering different parts of the district. The analysis also reveals a spatial interaction between high service zones and areas of fish lake distribution, which increases pressure on groundwater reservoirs. This emphasizes that the growing reliance on groundwater wells necessitates the adoption of effective strategies for the sustainable management of water resources in Daquq district

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Table (4): Areas served by wells in the study area

Areas Served (meters)	(Area (km2
500	53.70
1000	87.50
1500	80.80
2000	71.20

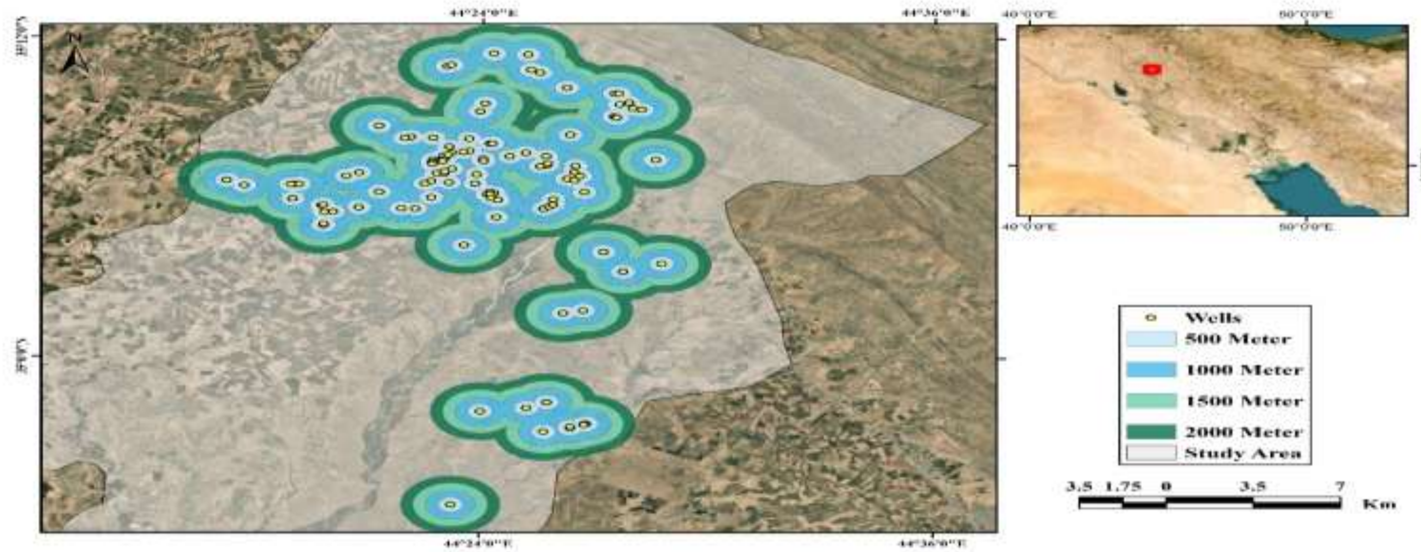

Figure (6): Map of the service ranges for groundwater in Daquq district - Kirkuk governorate

Results and Discussion

Morphometric changes in fish ponds and their reflection on the volume of water loss

Table (5) shows the changes in the number of fish ponds, their total area, and the volume of water stored in them, in addition to the depth of evaporated water and the volume of water loss during the study years (2016-2019-2024), reflecting the dynamics of fish expansion and its impact on water resources.

In 2016, the number of ponds reached about 334 basins, with a total area of 4,558,075 m² with a constant water depth of 1.5 m, resulting in a total water volume of approximately 6,837,112.5 m³. An evaporation depth of 1,363 m was recorded, resulting in a high water loss of 8,901,096.69 m³, indicating a clear effect of higher

In 2019, the number of fish ponds increased to 416, and the total area expanded to 7,425,625 m², raising the overall water volume to approximately 11,138,438 m³. Despite a decrease in evaporation depth to 1.199 m compared to 2016, the volume of evaporated water remained high, reaching about 6,212,656.24 m³.due to the increase in the total area of the basins.

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In 2024, the expansion continued significantly, with the number of fish ponds reaching 486 and the total area increasing to 13,311,675 m². Consequently, the overall water volume rose to approximately 19,967,513 m³. An evaporation depth of 1.234 m was recorded, resulting in a substantial water loss of about 16,546,412.51 m³, the highest during the study period. This reflects the cumulative impact of pond area expansion on water depletion rates.

In general, the results demonstrate a clear positive relationship between the increase in the number and area of fish ponds, on the one hand, and the rise in the total volume of water lost through evaporation, on the other. Although the water depth in the ponds remains constant at 1.5 m, the annually recorded evaporation depth represents a considerable proportion of the total depth. This indicates low water retention efficiency and high loss rates, particularly under the prevailing hot climatic conditions in the study area [14].

These data indicate that the unregulated expansion of fish lake construction has led to increasing pressures on water resources, particularly groundwater. This situation necessitates the adoption of regulatory measures and more efficient water management techniques to minimize water loss and enhance sustainability [15].

Table (5): Number of basins and their area (m²) and total water volume of basins and evaporators (m³) for the years (2016-2019-2024)

Year	Number of Aquariums	Depth of water in the basin (m)	Total area of basins (m²)	Total water volume of basins (m³)	Evaporated Water Depth (m)	Evaporated Water volume (m3)
2016	334	1.5	4558075	6. 837.112.5	1.363	8.901.096.69
2019	416	1.5	7425625	11.138.438	1.199	6.212.656.24
2024	486	1.5	13311675	19.967.513	1.234	16.546.412.508

Monthly Changes in Fish ponds Evaporation Rates for 2024

Table (6) and Figure (8) show the monthly changes in the depth of evaporated water and the volume of water loss from fish ponds during the period from April (4) to August (8), with the stable total area of the ponds at 13,311,675 m², which allows a direct comparison of the impact of monthly climate changes on evaporation rates.

The results indicate that the lowest evaporation values were recorded in April, with an evaporated water depth of about 0.161 m, resulting in a water loss of approximately 2,143,180.16 m³. By May, the evaporation depth increased to 0.215 m, and the volume of evaporated water rose to nearly 2,862,010.13 m³, reflecting the onset of the gradual rise in temperature.

This upward trend continues until the month of June (evaporation depth 0.257 m), and water loss growing to be approximately 3,421,100.48 m³ following intensified hot weather and more solar radiation received by soil surfaces during this interval. The most evaporation occurred during July (0.290 m evaporated water depth), accounting for 3,860,385.75 m³ of shallow aquifer water volume loss.

During August, the highest evaporation values of the study period were recorded, with an evaporated water depth of 0.320 m and a water loss volume of approximately 4,259,736 m³. These values reflect the peak influence of summer heat on exposed water bodies.

In general, the results show a clear direct relationship between the progress of the summer months and the high rates of evaporation, which confirms that fish ponds represent a major source of water waste during the hot months, especially in light of the stability of the water area and the expansion of the open areas. These findings are particularly important when linked to the heavy reliance on groundwater to recharge these basins, which compounds the pressures on the aquifer during the summer [16].

The data highlight the necessity to manage aquariums seasonally (mostly during hot peak months) in more efficient manner with respect to regulating operation, reducing surface areas and mitigate evaporation losses through evaporative policies which could help improve overall water sustainability of the study area [15].

Table (6): Volume of evaporated water from ponds for the year 2024

Months	Water Depth Evaporator (B)	Total Area For basins (m^2)	Volume of evaporative water (m^3)
4	0.161	13311675	2,143,180.158
5	0.215	13311675	2,862,010.125
6	0.257	13311675	3,421,100.475
7	0.290	13311675	3,860,385.75
8	0.320	13311675	4,259,736

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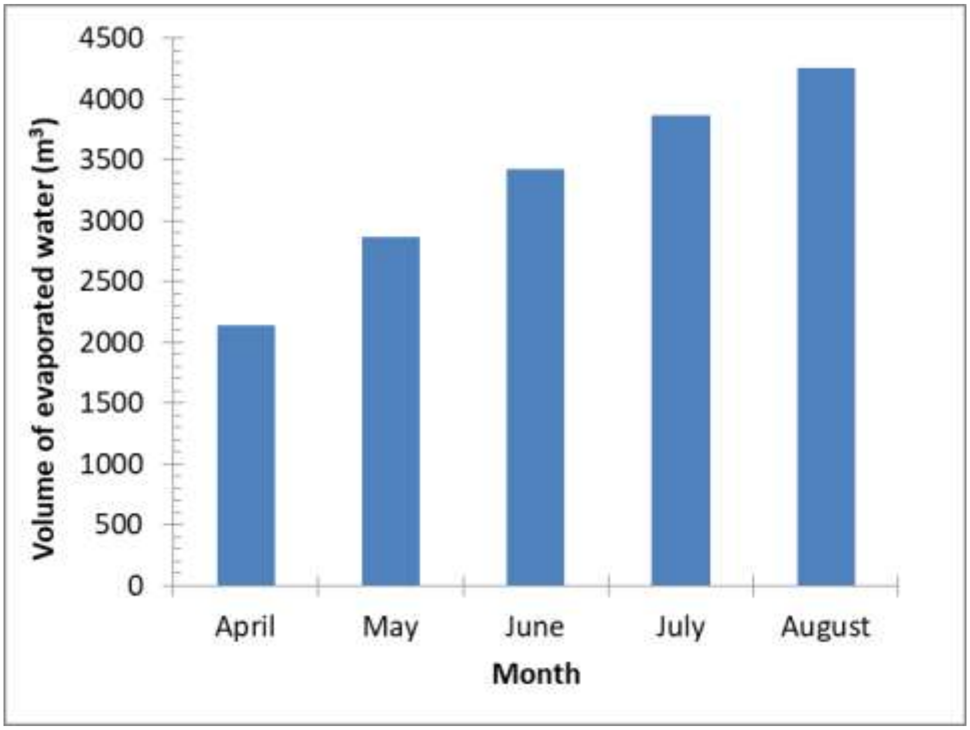

Figure 8: volume of evaporated water in 2024.

The monthly changes in evaporated water depth and volume water loss from fish ponds are shown in Table 7 and Figure 9 over the period of April to August, 2016. Total pond area was constant (4,558,075 m^2) enabling a direct comparison of how monthly climatic drivers influenced rates of evaporation [17].

The results show that the lowest evaporation values occurred in April, with an evaporation water depth of roughly 0.1756 m, indicating a loss of about 800397.97 m^3 of water owing to the comparatively milder climatic conditions at the beginning of the high thermal season.

This water evaporated slowly, as in May the evaporation depth has increased to 0.2133 m corresponding to an estimated volume of evaporated water amounting to around 972,237.40 m^3; this is synchronized with the gradual increase in temperatures associated with increased solar radiation. And relative humidity during this month.

During the month of June, this rising trend continued to be reflected along with a penetrating depth that reached 0.2493 m of evaporated water and a volume of water losses increased for more than one million cubic meters (m^3) reaching approximately 1,136,328.10 m^3.

Evaporation was at a maximum in July 2016 with an evaporation water depth of 0.4626 m and estimated total water loss over the month equal to 2,108,565.50 m^3 due peak summer temperatures and high solar radiation combined with the wide spread of exposed water bodies.

The evaporation depth dropped relatively to 0.2622 m, with an evaporated water volume of approximately 1,195,127.27 m^3 in August, which may reflect variability of climatic conditions or decrease and increase of wind speed

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Table (7): Volume of water evaporated from ponds for the year 2016

Months	Depth evaporated water (m)	Total Area Of ponds (m^2)	Volume of Evaporated water (m^3)
4	0.1756	4558075	800,397.97
5	0.2133	4558075	972,237.40
6	0.2493	4558075	1,136,328.10
7	0.4626	4558075	2,108,565.50
8	0.2622	4558075	1,195,127.27

Generally, the results show a clear monthly variation in evaporation rates, with highest rates of water loss recorded during the summer months, particularly in July, which confirming that fish ponds are a major source of water losing during hot periods. These results have particular importance when linked to the high dependence on groundwater to recharge these basins, as high evaporation rates increase the demand to extract water from the aquifer to compensate for the losses [18].

These data highlighted the need for effective seasonal management of fish ponds, with a focus on reducing water loss during the peak thermal months, which contribute in mitigating depletion of groundwater resources and enhancing their sustainability in the study area.

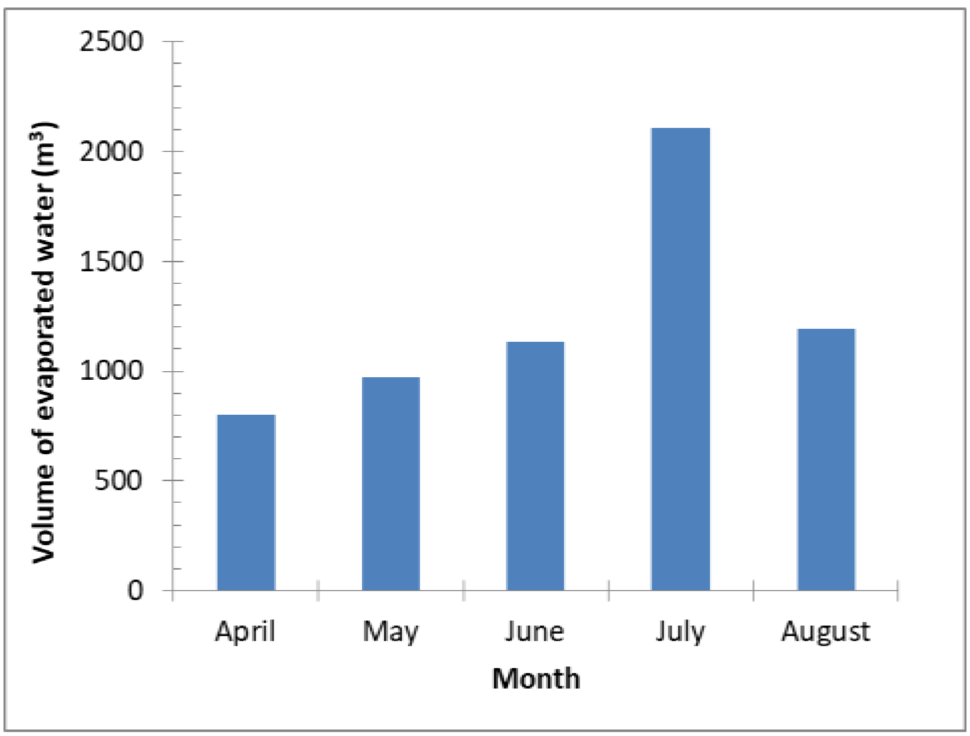

Figure (9): Volume of evaporated water from ponds for the year 2016

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Table (8) and Figure (10) show the monthly changes in the depth of Evaporated water and the volume of water loss from fish ponds in 2019 during the period from April to August, with fixing the total area of ponds at 7,425,625 m², which allows the analysis of the impact of seasonal climatic factors on evaporation rates directly.

The results indicate that the month of April recorded the lowest evaporation values during 2019, as the evaporated water depth reached about 0.1411 m, and resulted in a water loss of 1,047,755.69 m³, which reflects the relative moderation in climatic conditions during the beginning of the thermal season.

In May, the depth of evaporation increased to 0.2277 m, which led to clear increase in the volume of evaporated water to reach about 1,960,814.81 m^3, along with increasing temperature and solar radiation. This ascending trend continues during June, where the depth of evaporated water reaches 0.2852 m. the highest volume of water loss during that year to reach 2,117,788.25 m^3, which refer to the peaking thermal impact on waterbodies.

During July, a slight decrease in evaporation depth was observed to 0.2747 m, with a volume of evaporated water recorded 2,039,819.19 m³, which may be attributed to temporary changes in wind speed or relative humidity. This relative decline continued through August, when evaporation reached a depth 0.270 and resulted in a loss of water of its value. 2,004,918.75 M³. Generally, the results show that evaporation rates during 2019 were characterized by an upward gradient from spring to the beginning of summer, and then relative stability during the peak of summer, a pattern that reflects the interaction between exposed water bodies and prevailing climatic conditions. The high values of the volume of evaporated water also confirm that fish ponds are an important source of water waste, especially in light of the almost complete reliance on groundwater to compensate for this loss [19].

These results highlight the importance of seasonal management of fish ponds, especially during the summer months, to reduce evaporation water loss and reduce pressures on groundwater resources, thus contributing to enhancing water sustainability in the study area.

Table (8) shows the volume of evaporated water from the basins for the year 2019

Months	Depth of evaporated water (m)	Total area of ponds (m^2)	Volume of evaporated water (m^3)
4	0.1411	7425625	1,047,755.69
5	0.2277	7425625	1,690,814.81
6	0.2852	7425625	2,117,788.25
7	0.2747	7425625	2,039,819.19
8	0.270	7425625	2,004,918.75

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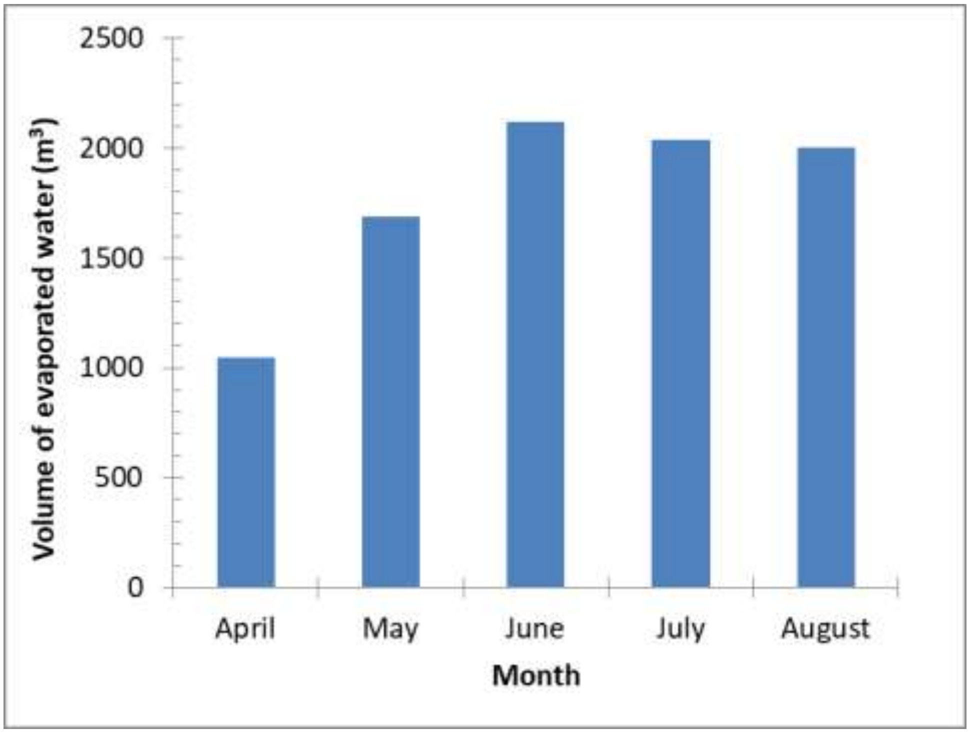

Figure (10): Volume of evaporated water from ponds for the year 2019

It is noticed from table 9 and figure 11 the variations in total volume of water in fish ponds and evaporated water losses during the years (2016, 2019, and 2024, as well as the percentage of water losses, that reflect the exposed pressure on water resources, particularly groundwater in the study area..

In 2016, the total volume of water used in fishponds was about 6,837,112.5 m³, while the volume of evaporated water was estimated to be about 6,212,656.2 m³, which represents a high percentage of loss of %90.87 of the total used water. This high percentage indicates low water use efficiency and high evaporation rates from exposed water bodies, especially under prevailing climatic conditions [20].

In 2019, the total volume of water increased to 11,138,437.5 m³, with an evaporation volume of 8,903,324.4 m³, with a percentage of 79.93%. For the absolute values of evaporated water, regardless of moderately lower proportional share of losses than in 2016, there was obvious increasing trends that includes extension of total area covered with ponds and continuing squeeze on water resources.

Total water volume was maximized in 19,967,512.5 m³ while evaporated water volume reached around 16,426,606.9 m³ offering a loss percentage of (82.27%) in fish ponds in the year of 2024. This increase in both total volume and evaporation during the same period reflects a direct result of extensive fish pond development, supplemented by persistent climate signals that enhance potential rates of evaporation.

Generally, the results show that the rates of water loss due to evaporation remained high throughout the study years, and did not fall below 79%, confirming that fish ponds represent one of the most prominent sources of water loss in the region, and these results are especially important in light of the reliance of these ponds mainly on groundwater, which exacerbates depletion rates and threatens the long-term sustainability of the aquifer [21].

These results also emphasize the urgent need to regulate construction and operation of fishponds, adopt more efficient methods of water management, beside the role of the specialist authorities in reducing unregulated expansion and reducing the negative effects of evaporation on water resources in Daquq district.

Table (9): Volume of water lost due to evaporation from fishponds during the study years

Years of study	Original total water volume (m^3) in ponds	Volume of evaporated water (m^3)	Percentage of losses from ponds %
2016	6837112.5	6212656.225	90.87
2019	11138437.5	8903324.375	79.93
2024	19967512.5	16426606.95	82.27

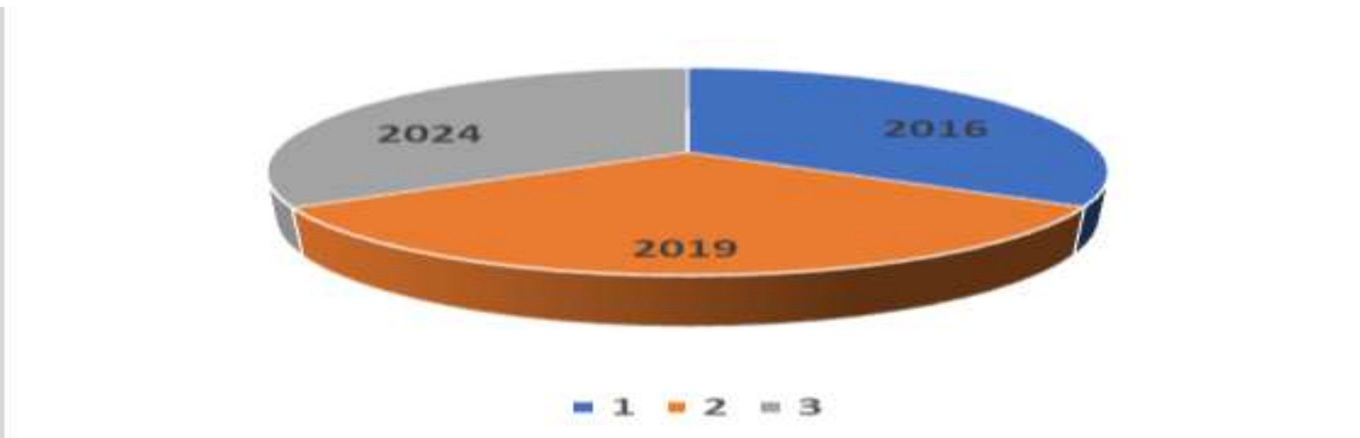

Figure (11): Percentage of evaporated water volume from the ponds for the period (2016-2019-2024)

Temporal Changes in Land Cover Categories in the Study Area (2016-2025)

Table 10 and figure 12 illustrate the land cover categories in study area during the period extended from 2016 to 2025. There was a clear spatial and temporal reflects the increasing effect of human activities especially the expansion in constructing fishponds on the patterns of land uses and water resources.

Related the plant cover, it is noticed the existence of clear increasing in its area from 4444.72 hectare in 2016 to 2840.44 hectare in 2019, then it is increased in 2024 to reach 3682 hectare, this is attributed to climatic variations in rainfall amounts and styles of agricultural management. In contrast, there was high increasing recorded in 2025 shows a clear variation in surface land characteristics, this was correlated with increasing surface moisture or

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changing land use during the monitoring period [22]

Related the arid lands, they recorded relative stability between 2016 and 2019, followed by a gradual decline by 2024, then a clear decline noticed in 2025, indicating that the other parts of this land have been converted to other uses, such as agricultural activities or artificial waterbodies associated with fishponds. Concerning rivers, their area remained constant at 748.89 hectares during the entire study years, which reflects the limited change in the natural surface water resources in the region, and confirms the dependence of the new water activities on non-surface sources, especially groundwater [23]. the fish ponds showed an accelerated increase from 1823.23 hectares in 2016 to 2970.25 hectares in 2019, and then to 5324.67 hectares in 2024, reflecting the significant expansion of ponds construction during this period. Whereas the recorded decrease in 2025 to 1110.82 hectares which may be attributed to regulatory factors and the monitoring efforts of the relevant authorities to prevent the establishment of fish ponds or the timing of satellite observations or the reclassification of certain water bodies, without canceling out the general trend that indicates increasing pressure on groundwater resources. These results confirm that land cover category changes in the study area are directly linked to human activities, especially startling aquarium unregulated expansion and highlights urgent needs to enhance monitoring mechanisms on applied remote sensing and GIS approaches for sustainable management of aquatic resources. [24].

Table (10): Categories of land cover for the study area

Ground Cover Categories	Are in hectares			
	2016	2019	2024	2025
Vegetation	4444.72	2840.44	3682	27620.04
The barren lands	8216.316	8262.042	7942.511	4333.671
Rivers	748.89	748.89	748.89	748.89
Fish ponds	1823.23	2970.25	5324.67	1110.82

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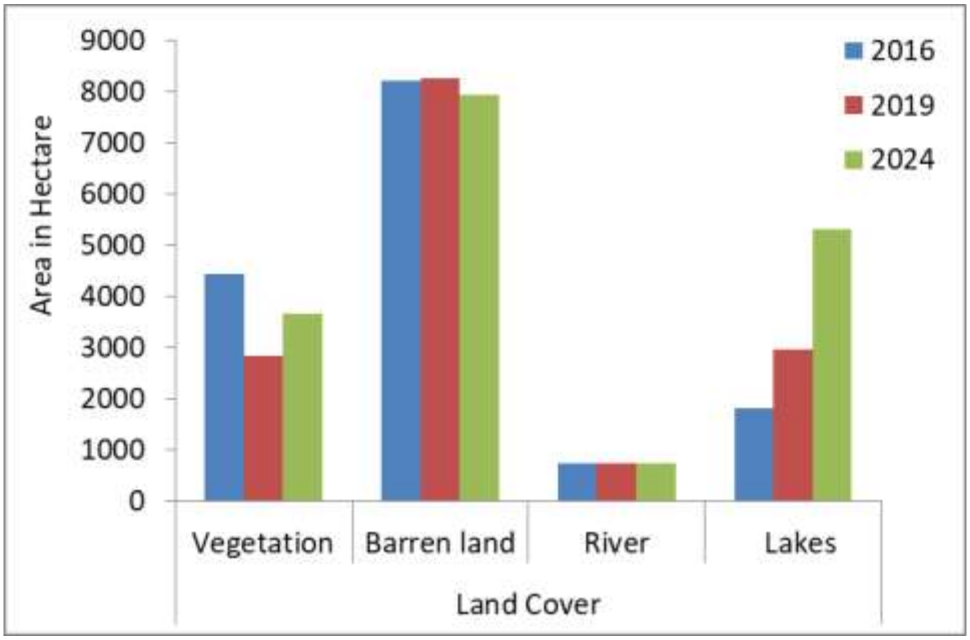

Figure (12): Chronology of the development of land cover in the study area for the years from 2016 to 2025

Quantitative analysis of the spatial distribution of land covers classes and surface water resources.

Table 11 shows the land cover in 2016

2016 - 06	
Description	Area (dunam)
Ponds	2970.25
Barren land	82620.42
plants	2840.44
Rivers	748.89

Table (11) and Figure (13) show the distribution of land cover areas in the region for 2016, measured in dunams, distributed over four main categories: ponds, arid lands, plant cover, and rivers.

Arid lands consisted the vast majority of the area which was about 82,620.42 dunams, indicating the predominance of desert character or weak vegetation cover in the area while ponds cover an area 2,970.25 dunams, which was the highest among the non-arid categories reflecting the existence of important water resources that can be used for water management or agriculture.

The vegetation cover is only 2,840.44 du, which indicates the limited green areas compared to arid lands which is an important indicator for studying land reclamation or assessing environmental resources. The rivers were also kept a stable area of 748.89 du, indicating the stability of river networks in the region during this period [25].

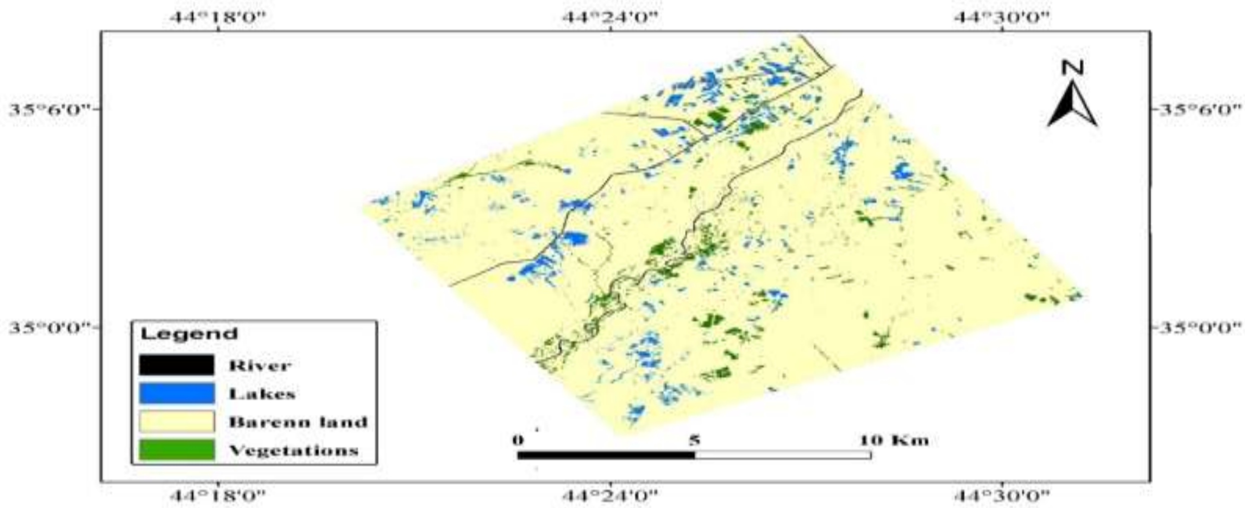

Figure (13): Spatial Land Cover Distribution Map for 2016

Table 12 shows the spatial distribution of land cover classes in 2019

2019 - 06	
Description	Area (dunam)
Ponds	1823.23
Barrenland	82163.16
plants	4444.72
Rivers	748.89

It is observed through Table (12) Figure (14) that Arid lands cover a large area of 82,163.16 dunams, which was vast majority of the area, reflecting the limited land suitable for agricultural exploitation and indicating significant pressure on natural resources. While the plant cover reached 4,444.72 dunams, which reflects the decline in plant cover and indicates potential hydrological pressures and a shortage of water available for agricultural activity and pastures [26]. Ponds covers an area of 1,823.23 dunams constituting a relatively small part of the total area, indicating the limited natural water reservoirs in the area. While representing Watercourses have the lowest component with an area of 748.89 dunams, which reflects the weakness of the surface water network and the increase in dependence on groundwater, which is directly related to the problem of depletion and

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encroachments on groundwater resources addressed in the manuscript [26].

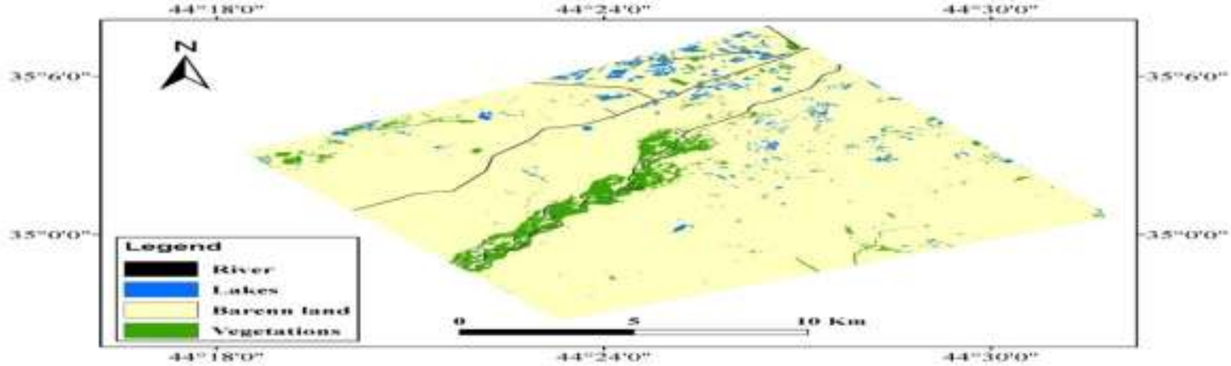

Figure (14): Land uses classification map

(Ponds-Arid Lands-plant cover-Rivers) for 2019

Table 13 shows the spatial and relative distribution of land cover classes in Daquq district in 2024

2024	
Description	Area (dunuam)
Ponds	5324.67
Barren land	79425.11
plants	3682
Rivers	748.89

Through Table (13) and Figure (15), it is clear that the study area can be classified into four main cadastral categories, represented by barren or (arid) lands, artificial fish ponds, plant cover, and watercourses.

First: Spatial dominance of barren lands

The list of land uses in the study area covered an estimated area of 79,425.11 dunams. This spatial dominance is attributed to a set of interacting natural and human factors, most notably the climatic characteristics. The study area lies within the semi-arid to arid zone, characterized by low annual rainfall and high evapotranspiration rates [27], the limitation of natural vegetation development is further exacerbated by water depletion. The spatial expansion of barren lands indicates a decline in groundwater levels due to excessive pumping, which has negatively affected vegetation cover and agricultural activity in the area. Environmental deterioration could also be one of the causes for such large desertification zones, by consequence of groundwater resources invasion and their overexploitation [28].

Second: the biomimetic ponds as indicators of hydraulic pressure.

The second in the area with an area of 5,324.67 dunams it shows artificial fish farming ponds. The present study is particularly interested in this particular category since it depends entirely on

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the efforts to pump groundwater from wells discharging high hydraulic pressure over aquifers. Due to the high tendency of loss by evaporating and seeping, these ponds require massive amount of water irrigated under the region's wheezing climate. Additionally, their uncontrolled spatial distribution regardless of the hydrogeological capacity of the aquifers is indicative of groundwater level declines and deterioration in water quality [15].

Third: decline in vegetation covers as hydro environmental indicator

Vegetation cover, statistically speaking, occupies 3,682 du in the areas we studied, ranking third among land cover categories. It further highlights the finite water resources by showing how decreasing vegetative cover is associated with groundwater extraction and insufficient surface water supply to enable increased agriculture or grazing. Moreover, the competition between agriculture and aquaculture for limited water supplies with practices that are not sustainable indicates the early phases of desertification and environmental degradation [29].

Fourth: Reduction of surface watercourses

Surface waters account for 748.89 du, the lowest percentage among land cover indicators. This limited range underscores the vulnerability of the hydrographic network and low flow rates caused by repeated droughts and uncompromising water abstraction. This induces pressure on aquifer systems, leading to the depletion and overexploitation problems studied in this paper.

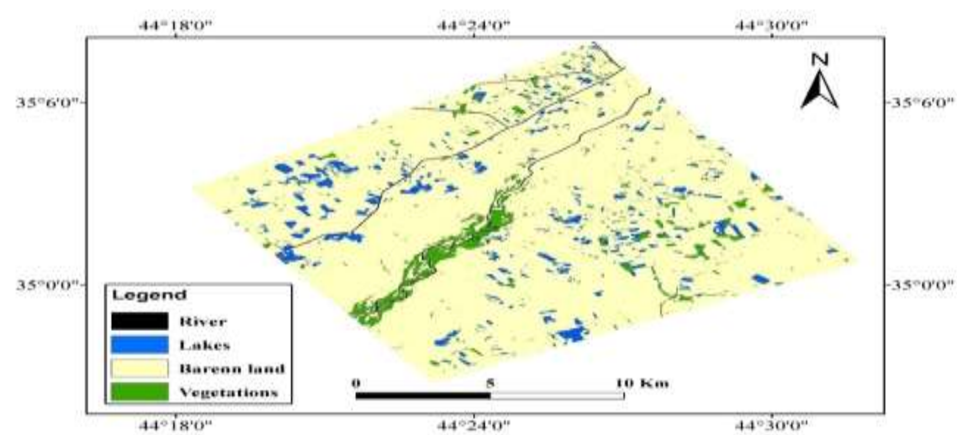

Figure (15): Spatial Analysis Map of Land Use in the Study Area in 2024

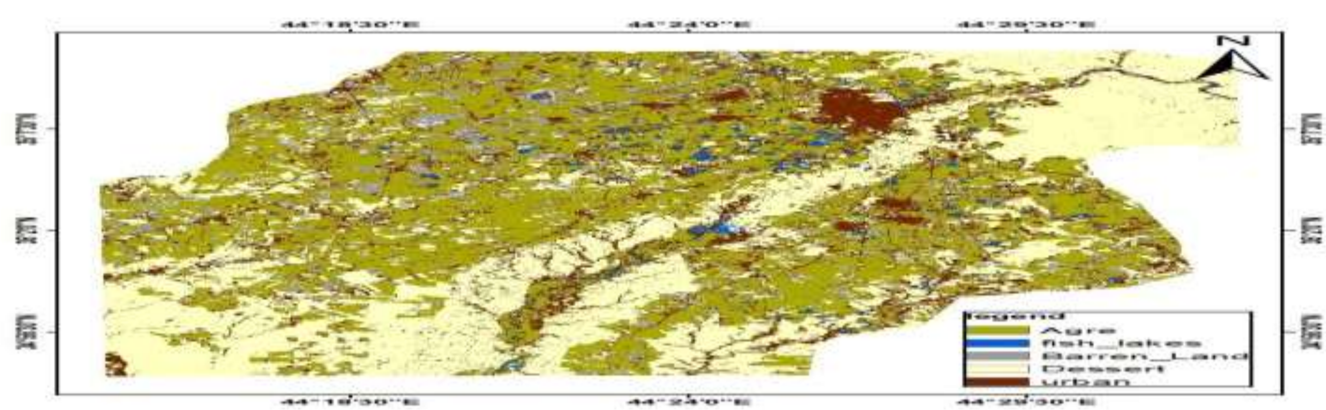

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Figure (16): Map of the land cover in the study area in 2024

CONCLUSION AND RECOMMENDATIONS

Summary of main results

During the time frame of this study, an obvious increase in fish ponds due to the increase in both number (fish pond) and area occurred as revealed by results from Daquq district, Kirkuk governorate. Remote sensing analyses established substantial expansion of artificial aquatic surfaces, simultaneously accompanied regional vegetation coverage decrease along with a detectable transition in land use trends. Moreover, the results highlight the great reliance on groundwater resources by irrigation fish ponds due to a wide distribution of deep wells in the study area.

Impacts on groundwater resources

Reported over-abstraction from deep wells threatens aquifers around Daquq district with uncontrolled expansion of aquaculture ponds. Unless carefully managed with regulatory oversight, continued overdraft is projected to reduce groundwater tables and water quality in the medium- to long-term. Such trends threaten the sustainability of water resources while also undermining both agricultural productivity and ecological balance in the region — with potentially a big impact on food security, employment, and ecosystem services.

ROLE OF REMOTE SENSING AND GIS TECHNOLOGY FOR MONITORING ENCROACHMENTS:

The current study highlights the importance of remote sensing and GIS technology in land use change monitoring and water resources protection. Sentinel-2 and Landsat imagery derived from water and vegetation spectral indices showed high accuracy in separating aquaculture ponds from natural viz. natural sites. Longer-term trends could be evaluated using Landsat due to its longer temporal archive and more recent changes assessed with Sentinel-2. The combination of geospatial outputs with field observations greatly improved the accuracy and validity of the results.

ADMINISTRATIVE AND PLANNING INDICATORS:

This study highlights an urgent requirement for strong regulatory regimes to sustainably manage groundwater extraction in Daquq and its surface and aquaculture pond related abstractor operations. It places geospatial technologies as a strategic asset for implementing data-driven decision making by suplies accurate databases and reference maps that can allow early detection of illegal practices and strengthen the governance of water resources projects.

RECOMMENDATIONS

- Longer-term research to monitor groundwater responses in terms of both level and quality, and apply hydrological analysis along with predictive models to evaluate consequences of ongoing fish pond development.
- Scaling the approach to other regions under similar pressures on water resources in order to embed the methodology and national groundwater management strategies.
- Initiating an inventory and numbering campaign for all ponds (owner, geolocation, area, water source/well/pump/electricity). This is an important measure, since Daquq has thousands of ponds but only seven that are licensed, according to the Daquq Water Resources Department.

- Placing a temporary freeze on construction of new ponds (or expansion of existing ponds), particularly those

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reliant on wells, until the inventory is finalized.

- Taking a simple operational policy decision: renewals and expansions and drilling/equipping of new wells for fish ponds should not be tolerated unless subsequently registered in an official geospatial database.
- Establishment of a new conditional license, at the governorate level, and which will be granted only if four operational conditions have been met:

1. Identifying which water source (groundwater/surface) is associated with a particular quota.
2. Installation of monthly reading (manual/electronic) water intake meters to prevent wastage.
3. The detection of a plan for the management and drainage of water to prevent contamination of soil and drains.
4. For aquifer-stressed areas, introducing environmental impact assessment for existent and new projects.

- Adopt initiatives towards saving water and avoiding its wastage like switching to steel-lined ponds.
- Adoption of mandatory standards for reducing evaporation and seepage losses by:
  - Soft earth ponds lining to avoid leakage.
  - Windbreaks and Non-water consuming vegetation belts to reduce evaporation.
  - Using smaller and somewhat deeper ponds to decrease the area of exposed surfaces of water.
  - Removing water plants spaces by eliminating water-absorbing aquatic vegetation.

Progressive transition to less water-intensive technologies (ie, lined ponds/closed systems) assisted by incentives such as a microloan & waiver of fees for upgrading licensed farms without standard lined ponds or recycling/filtration systems broke up on the basis of their contribution to gradually scaling back and reduce reliance on continuous pumping to meet this site's development goal and moving from over-pumping plus evaporation rates provisionally credited with superior productivity per cubic meter.

– Use monthly satellite maps of artificial water bodies to detect any newly built or expanded ponds and check it against the licensing database by establishing a joint hydro-agricultural monitoring unit to be composed at least from (Governorate/Water Resources/Agriculture/Environment/Electricity). This helps clarify the role of institutions involved, strengthen water governance.

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