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Purposeful scientific research as a pillar of sustainable development

The reality of groundwater in Kirkuk Governorate under climate change, increasing demand for groundwater, by using of artificial intelligence to better management groundwater in the governorate

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ABSTRACT

Due to global climate change, which has affected all natural phenomena, including groundwater, which has doubled and groundwater levels have decreased significantly in Kirkuk Governorate, there is a lack of rainfall and a high demand for groundwater, which has caused groundwater levels to decrease significantly. Therefore, the use of artificial intelligence (AI) to determine groundwater levels and improve groundwater quality has become a current need and a demand for its use to find appropriate methods for better groundwater management in Kirkuk Governorate. Using Geographic Information System (GIS) and remote sensing software to create maps and charts of groundwater levels in different periods (2001-2005), (2006-2010), (2011-2015), (2016-2020) and (2021-2025) and the amount of total dissolved solids (TDS) in the same period mentioned above. For this purpose, data were integrated to know the rate of fluctuation of groundwater level during the period from 2001 to 2025 using the Inverse Distance Weighting (IDW) technique based on GIS to create water level maps. The results showed that groundwater levels have decreased significantly due to global climate change, and total dissolved solids (TDS) in groundwater have increased due to low rainfall in the past few years (drought). The study showed a decrease in all five stages in Kirkuk Governorate, with the situation being worst in the areas of Qarahanjir, Goldara, Shwan, Hawija, Laylan, and Daquq, where groundwater was rapidly depleted. Based on the results, groundwater levels fluctuated between 52 and 90 meters in the areas of Qara Hanjir, Goldara, and Laylan, and between 55 and 105 meters in the areas of the center of Daquq district and its surroundings, Rashad sub-district, Mir Isfahan sub-district, Qara Salem, the center of Shwan sub-district, and south of Kirkuk city towards Hamrin. Groundwater levels were found to fluctuate within a relatively narrow range of 15–36 meters in the Hawija and Dibis districts, and between 18 and 40 meters in the areas north and northeast of Shwan sub-district, Kirkuk city center, Taza Khurmatu sub-district, and Riyadh and Abbasi sub-districts, respectively. The primary cause of this decline in groundwater levels was the pumping of tube wells from groundwater resources, which exceeded natural recharge. Furthermore, rapid urbanization has led to a decline in the rate of infiltration in recent years. Therefore, the use of artificial intelligence to identify areas where groundwater levels have fallen and to find the necessary groundwater management solutions is both beneficial and necessary, resulting in accurate and cost-effective information and informed decision-making in addressing the water shortage problem in Kirkuk Governorate.

Keywords: Groundwater, Climate Change, Artificial Intelligence (AI), Groundwater Management, Kirkuk Governorate.

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1- Introduction

Groundwater is a vital water resource for humanity. Groundwater provides drinking water, in whole or in part, for up to 50% of the world's population and accounts for 43% of all water used for irrigation. Worldwide, only 2.5 billion people rely on groundwater resources to meet their basic daily water needs. The Earth's population, estimated at approximately 8 billion in 2020, is expected to reach 11 billion by 2100 [1]. Humans will have to learn to produce enough food without destroying the soil, water, and climate. This has been called the greatest challenge humanity has faced. Sustainable groundwater management is at the heart of the solution. Scientific understanding and sound management of groundwater are essential, as groundwater can mitigate the problem if we seek to use and replenish it responsibly [2]. Groundwater. Although hidden beneath the Earth's surface, groundwater constitutes 99% of the Earth's liquid freshwater and plays an important role in the water cycle. Rivers, lakes, and wetlands are surface manifestations of groundwater, exchanging flow with the aquifer, which replenishes them when they need water and takes over some of its flow when surface water is in excess [3]. Groundwater also controls many features on the Earth's surface. The depth of the water table is partly responsible for the different types of plants that occupy different locations along the slopes from hill to valley, as only drought-tolerant plants can survive on dry hillsides, and water-tolerant plants live near streams [4]. The dissolution of carbonate rocks by flowing groundwater creates caves and sinkholes. In desert environments, groundwater drainage forms oases that provide habitats for animals and plants.

2- Study Area

The study area is located in the northeastern part of Iraq between latitudes (34° 40' - 36° 00') and longitudes (43° 15' - 44° 55'). The area of the study area is approximately (6,779) Km^2 (Figure 1) and its elevation ranges between 233 and 1,204 meters above sea level. It is bordered to the north by Erbil Governorate, to the east by Sulaymaniyah Governorate, and to the south and west by Tikrit Governorate.

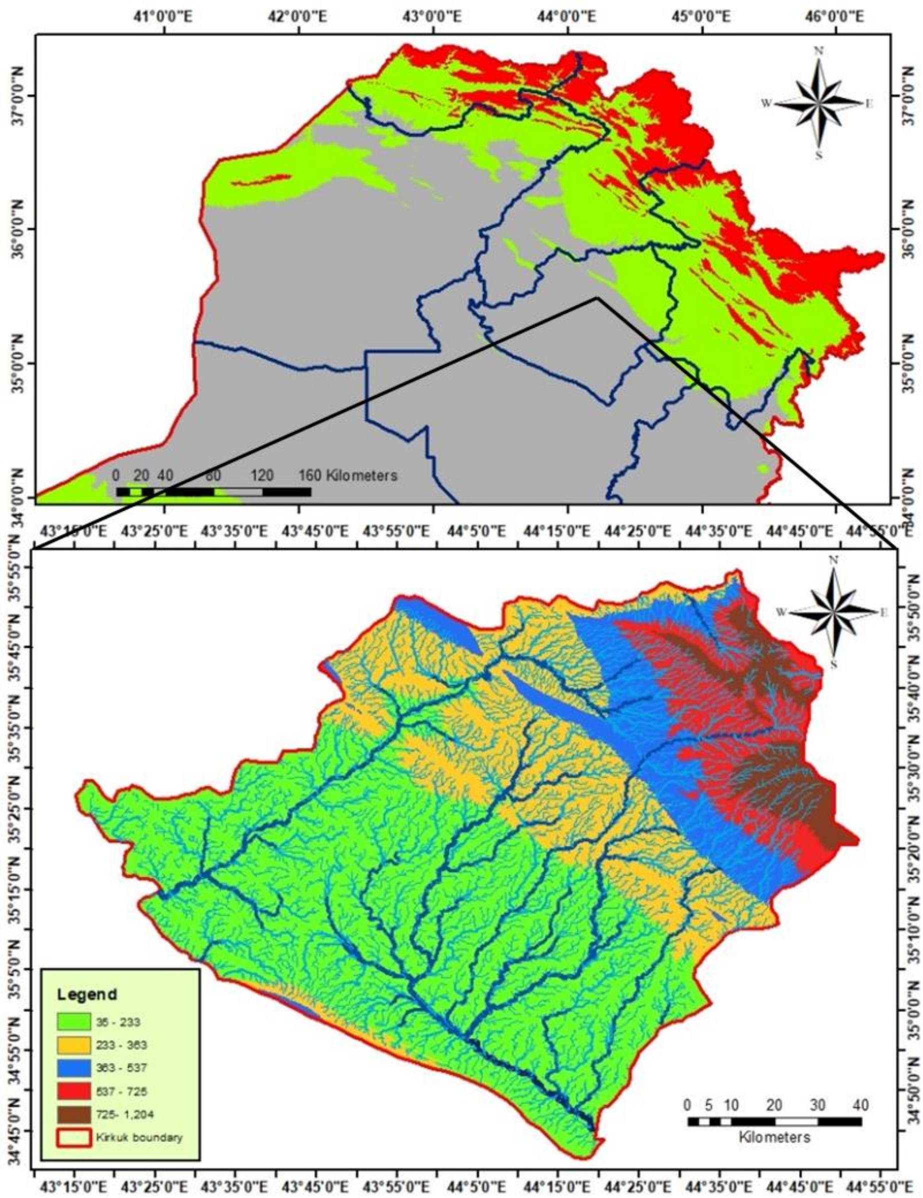

Fig. 1. Study area and topographic map of Kirkuk

3- Methodology

Data Preparation and Analysis: Information on the 2,000 wells drilled in Kirkuk Governorate between 2000 and 2025, taken from the Kirkuk Branch of the General Commission for Groundwater, was entered into a GIS program. The information included their location names, coordinates, discharge, depth, length (submersible pipes), and water quality. The data were entered into Microsoft Excel 2010, along with the groundwater depth (static and dynamic), electrical conductivity (EC), and total dissolved solids (TDS), and the wells were projected onto maps. To process the data, two programs were used: Arc GIS 10.4 for GIS data processing and mapping. The interpolation technique known as Inverse Distance Weight (IDW) was used to produce contour maps and assess water level variation. The other program used in data processing is Microsoft Excel 2010, and with the help of this program, graphs were produced for each location and for each period (2001-2005), (2006-2010), (2011-2015), (2016-2020), (2021-2025) and (2000-2025) as in figures (3-32).

4- Geological Area

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The study of the clastic nature of rocks and their structural nature is one of the most important natural factors affecting the qualitative and quantitative characteristics of groundwater. This study helps determine the locations, depths, and spatial extent of groundwater reservoirs, and determines the physical and chemical properties of groundwater. The different nature of rock formations, including the presence of cracks and joints, affects the hydrological characteristics of groundwater reservoirs, as well as their variation in quality, characteristics, and properties, as they pass through rock formations of varying permeability and porosity. This contributes to the dissolution of the minerals and salts in these rocks, which requires a detailed study of the rock formations that have contributed to shaping the characteristics and properties of the water they contain [5].

Stratigraphic Sequence:

Through stratigraphic studies, it is clear that a group of geological formations exist, as follows:

A- Al-Fatah Formation (Middle Miocene): This formation is found in the Kirkuk structure. Its sediments are characterized by being cyclic and contain various rocks, such as limestone. The thickness of this formation varies between 64 and 818 meters [6]. The fact that this formation contains a large number of cracks and fractures filled with sand gives it a high capacity for storing groundwater. However, its high gypsum content has had a negative impact on the water within it. The dissolution of dolomitic limestone rocks in the water makes them rich in magnesium and calcium compounds [7]. This has resulted in an increase in the percentage of salts in the groundwater within this formation.

B- Injana Formation (Upper Miocene): This formation is exposed along the Kirkuk Formation. The characteristic of this formation is the succession of sandstone and mudstone rocks with thin layers of limestone and secondary gypsum. The thickness of this formation varies clearly from one region to another. Its thickness reaches (36) meters in the northern parts and (153) meters in the central parts at the Baba Dome, then it increases towards the south to reach (398) meters [8]. This formation enjoys its permeability and great storage capacity and high productivity, which makes its water suitable for most uses due to the low solubility of its components.

C- Al-Muqdadiya Formation (Upper Miocene-Pliocene): The Injana Formation overlies the Kirkuk structure conformity and appears east of the Kirkuk structure within the areas surrounding the Alton Kopri Plain and on both sides of the concave folds, with the exception of the Khalkhalan Dagh Mountain. It disappears in the plain areas under the cover of Quaternary sediments. Its most important components are coarse sandstone with siltstone, mudstone, and layers of successive mudstones. The thickness of the formation reaches (200) meters in the southern and western directions and (456) meters in the parts close to the Bai Hassan Formation. Its hydrological importance lies in the high permeability of its components, which allows for the presence of abundant groundwater reservoirs that receive continuous recharge from surface water or other groundwater reservoirs through hydraulic connection to those reservoirs.

D- Bai Hassan Formation (Pliocene): This formation appears in the form of rugged terrain in the northeastern parts of the study area, with the exception of the Khalkhalan Dagh Mountain, in addition to its appearance in some valleys. Its thickness exceeds (100) meters in Alton Kopri [9]. This formation contains a layer of mudstones with a thickness ranging between (50-80) meters, intermingled with sandstone and clay. The thickness of this formation varies depending on the nature of the sedimentary environment, ranging between (395-790) meters in Baba Dome. Given the thickness and components of this formation with good porosity and permeability, it constitutes an important reservoir for groundwater with good quality and economic quantities.

E- Quaternary sediments (Pleistocene-Holocene): These sediments cover most parts of Kirkuk Governorate, and include (gravel, sand, silt, and clay in an overlapping manner and in varying proportions from one region to another, as they include Pleistocene-Holocene sediments, which are sometimes difficult to distinguish between due to the lack of a clearly defined dividing line [10]. These sediments are characterized by containing groundwater in large quantities, and this is due to the layer of its components with coarse grains that allow water to penetrate, and it has the ability to store it in large quantities, which made them the best groundwater reservoirs in terms of storage, productivity, and fixed and moving levels.

5- Discussion and Conclusion

A- The period from (2001-2005)

During this period, (275) wells were used, which were drilled by the General Commission for Groundwater, Kirkuk Branch. From the map, it is clear to us that the depth level to groundwater (static water) in Kirkuk Governorate for the period (2001-2005) ranged from zero, which represents artesian, to 65 m, representing the areas with high depth levels to groundwater in the Qara Hanjir area, which is attributed to the quality of the water-bearing layers and the composition of the area, and the Goldara area, which is attributed to the excessive withdrawal of groundwater for agriculture, and the area south of Kirkuk city, as shown in figure (2A). The level of depth to groundwater (dynamic water) in Kirkuk Governorate for the period (2001-2005) ranges between 2 to 107 m and the areas with large levels of depth to groundwater are represented in the areas of Qara Hanjir, Goldara, Laylan, Shwan and south of Kirkuk city as shown in figure (2B) and figure (2C) The graphical chart of both depth to groundwater (static water and dynamic water). The level of dissolved solids in the groundwater in Kirkuk Governorate for the period (2001-2005) ranged between 172.16 to 6592 mg/L. The areas with high levels of dissolved solids in the groundwater are in the areas south of Kirkuk city towards the Hamrin formation, as shown in figure (2D) and figure (2E), the graphic chart of the concentration of dissolved solids in the groundwater.

B- The period from (2006-2010)

During this period, (257) wells were used, which were drilled by the General Commission for Groundwater, Kirkuk Branch. From the map, it is clear to us that the depth level to groundwater (Static water) in Kirkuk Governorate for the period (2006-2010) ranged from zero, which represents artesian, to 100 m, and the areas with high depth levels to groundwater are represented in the areas of Qara Hanjir, Goldara, and west of Kirkuk city, as shown in figure (3A). The depth level to groundwater (dynamic water) in Kirkuk Governorate for the period (2006-2010) ranges between 5 to 160 m. The areas with large depth levels to groundwater are represented in the areas of Qara Hanjir, Goldara, Dibis, the upper part of Shwan and a part of the south of Kirkuk city, as shown in figure (3B) and figure (3C), the graphical chart of both depth to groundwater (static water and dynamic water). the level of dissolved solids in the groundwater in Kirkuk Governorate for the period (2006-2010) ranged between 211.2 to 11072 mg/L. The areas with high levels of dissolved solids in the groundwater are in the areas south of Kirkuk city towards the Hamrin formation, as shown in figure (3D) and figure (3E), the graphic chart of the concentration of dissolved solids in the groundwater.

C- The period from (2011-2015)

During this period, (348) wells were used, which were drilled by the General Commission for Groundwater, Kirkuk Branch. From the map, it is clear that the depth level to groundwater (static water) in Kirkuk Governorate for the period (2011-2015) ranged from zero, which represents artesian, to 118 m. The areas with the highest depth levels to groundwater are Qara Hanjir, Goldara, Laylan, and part of southern Kirkuk, as shown in figure (4A). The depth level to groundwater (dynamic water) in Kirkuk Governorate for the period (2011-2015) ranges between 7 to 215 m. The areas with large depth levels to groundwater are represented in the areas of Qara Hanjir, Koldara, Shwan Junction, Qara Salem, Laylan, Shwan District, and part of the south of Kirkuk city, as shown in figure (4B) and figure (4C), the graphical chart of both depth to groundwater (static water and dynamic water). The level of dissolved solids in groundwater in Kirkuk

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Governorate for the period (2011-2015) ranged between 174.72 to 17411.84 mg/L. The areas with high levels of dissolved solids in groundwater are in the areas south of Kirkuk city towards the Hamrin structure, as shown in figure (4D) and figure (4E), the graphic chart of the concentration of dissolved solids in groundwater.

D- The period from (2016-2020)

During this period, (36) wells were used, which were drilled by the General Commission for Groundwater, Kirkuk branch. Due to the harsh conditions the country has been experiencing with the emergence of the terrorist organization ISIS and its control over the provinces of Nineveh, Anbar, Tikrit, and large parts of Kirkuk, as well as the spread of the coronavirus and the imposition of a curfew across the province, not many wells have been drilled during this period. From the map, it is clear to us that the depth level to groundwater (static water) in Kirkuk Governorate for the period (2016-2020) ranges between 6 to 126 m. The areas with high depth levels to groundwater are represented in the regions of Qara Hanjir, Laylan, Goldara, and Qara Salem, as shown in figure (5A). The depth level to groundwater (dynamic water) in Kirkuk Governorate for the period (2016-2020) ranges between 20 to 169 m, and the areas with large depth levels to groundwater are represented in the areas of Qara Hanjir, Goldara, Mafraq Shwan, Qara Salem, Laylan and Mir Isfahan, as shown in figure (5B) and figure (5C), the graphical chart for both depth to groundwater (static water and dynamic water). The level of dissolved solids in groundwater in Kirkuk Governorate for the period (2016-2020) ranges between 218.88 to 2329.6 mg/L. The areas with high levels of dissolved solids in groundwater are in the areas of Panja Ali (Laylan Road), Daquq and south of Kirkuk city towards the Hamrin structure, as shown in figure (5D) and figure (5E), the graphic chart of the concentration of dissolved solids in groundwater.

E- The period from (2021-2025)

During this period, (236) wells were used, which were drilled by the General Commission for Groundwater, Kirkuk branch. Also, due to the financial conditions and austerity that the country went through during this period, not many wells were drilled during this period. From the map, it is clear to us that the depth level to groundwater (static water) in Kirkuk Governorate for the period (2021-2025) ranges between 2 to 108 m. The areas with high depth levels to groundwater are represented in the regions of Qara Hanjir, Koldara, Laylan, Shwan, and Mir Isfahan, as shown in figure (6A). The depth level to groundwater (Dynamic water) in Kirkuk Governorate for the period (2021-2025) ranges between 8 to 198 m, and the areas with large depth levels to groundwater are represented in the areas of Qara Hanjir, Goldara, and Shwan Junction, as shown in figure (6B) and figure (6C), the graphical chart for both depth to groundwater (static water and dynamic water). The level of dissolved solids in groundwater in Kirkuk Governorate for the period (2021-2025) ranges between 197.12 to 5703.68 mg/L, and the areas with high levels of dissolved solids in groundwater are represented in the Rashad and Daquq areas and south of Kirkuk city towards the Hamrin structure, as shown in figure (6D) and figure (6E), the graphic chart of the concentration of dissolved solids in groundwater.

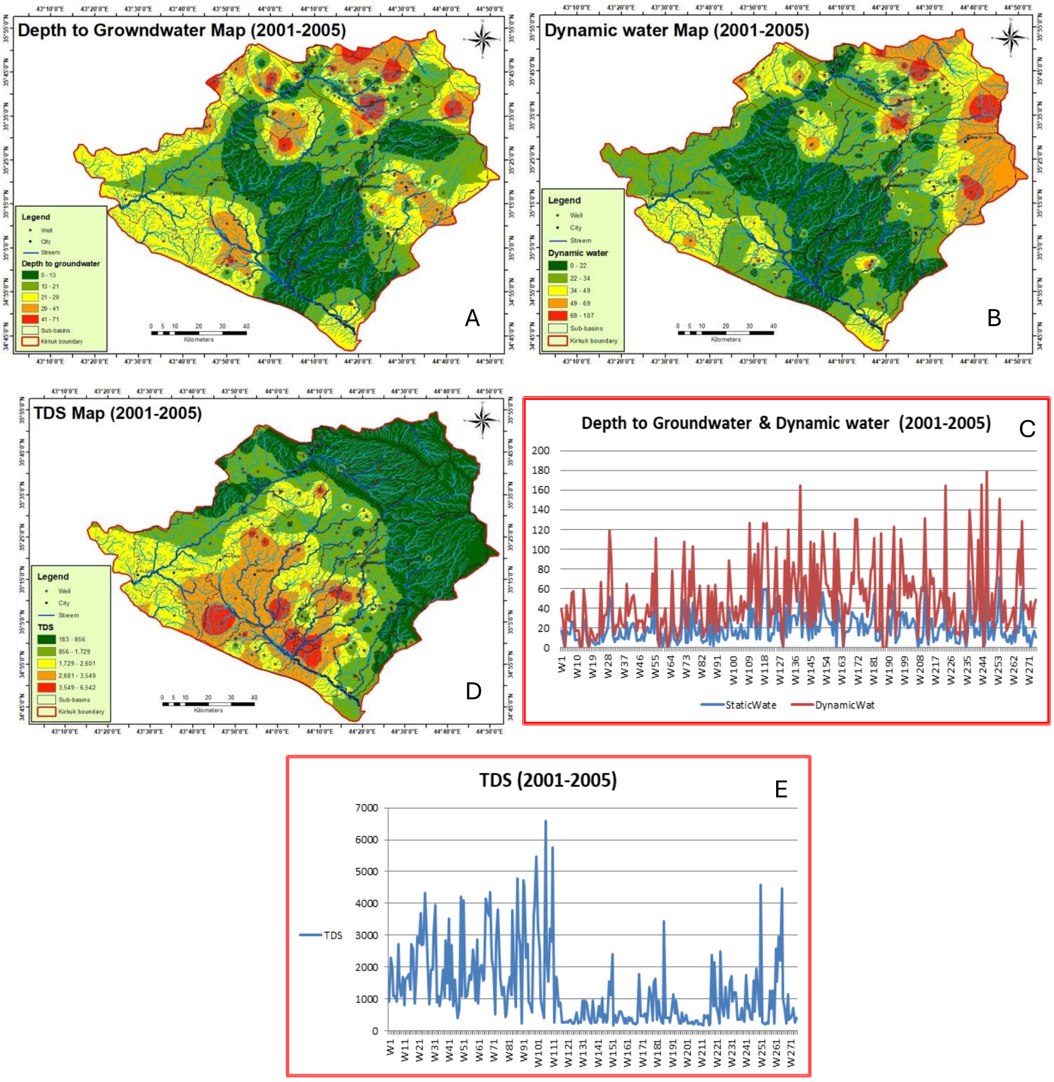

Fig. 2. Depth to groundwater maps and graphs (static, dynamic water and TDS) for the period (2001-2005)

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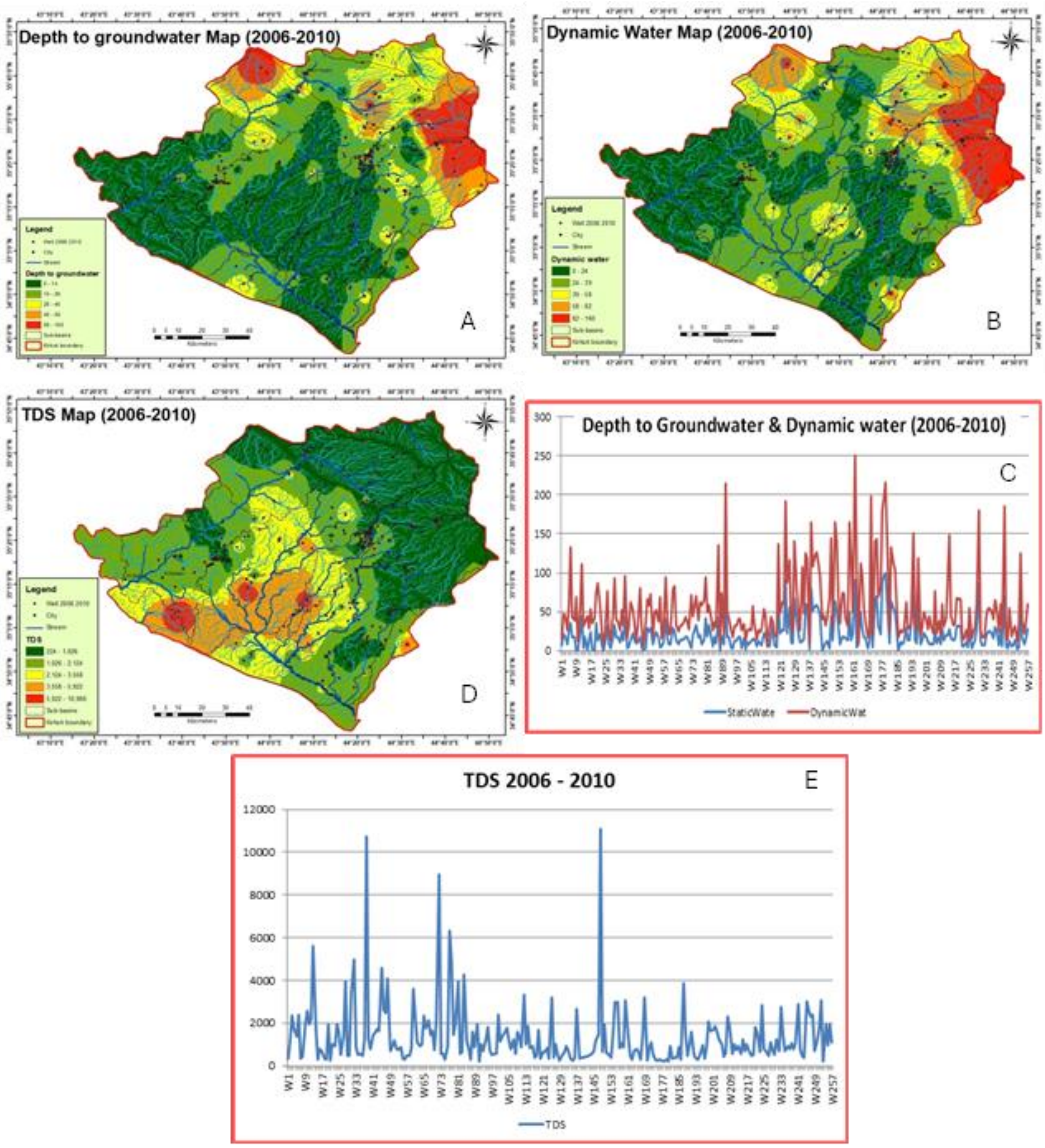

Fig. 3. Depth to groundwater maps and graphs (static, dynamic water and TDS) for the period (2006-2010)

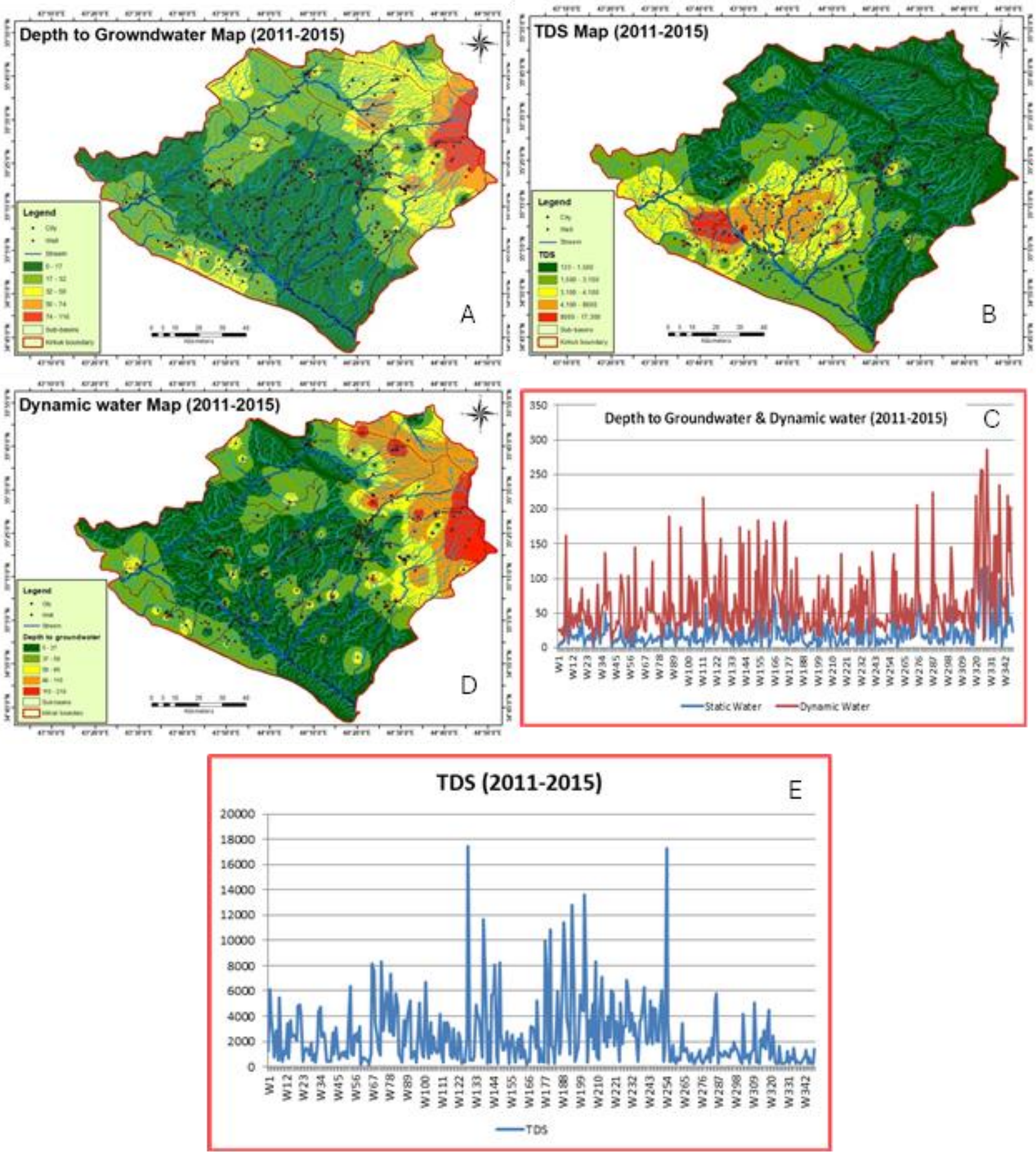

Fig. 4. Depth to groundwater maps and graphs (static, dynamic water and TDS) for the period (2011-2015)

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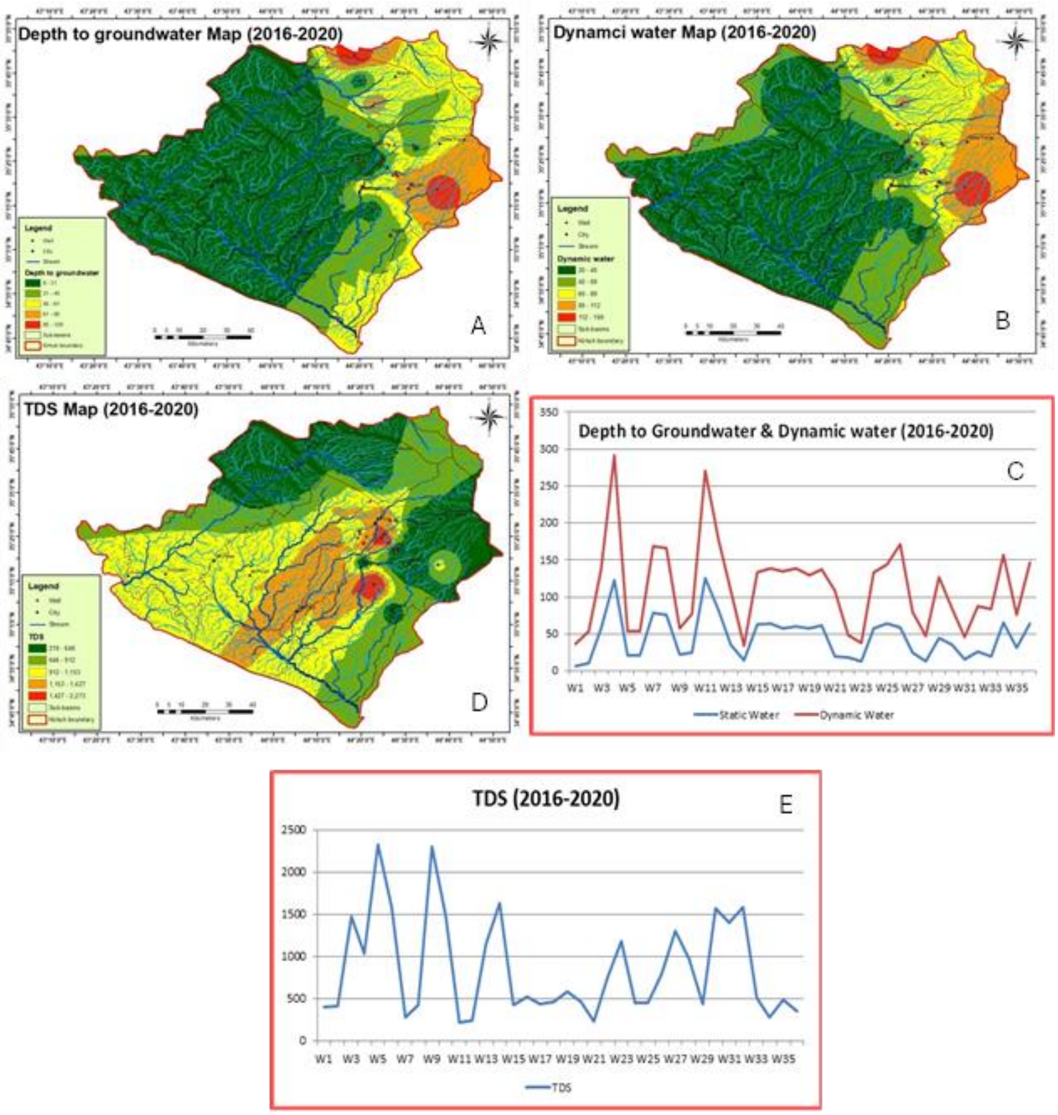

Fig. 5. Depth to groundwater maps and graphs (static, dynamic water and TDS) for the period (2016-2020)

F- The period from (2000-2025)

During this period, (1947) wells were used, which were drilled by the General Commission for Groundwater, Kirkuk branch. From the map, it is clear to us that the depth level to groundwater (static water) in Kirkuk Governorate for the period (2000-2025) ranges between 0, which represents artesian, to 126 m, and the areas with high depth levels to groundwater are represented in the regions of Qara Hanjir, Goldara, Laylan, Shwan, Qara Salem, Dibis, and southern Kirkuk, as shown in figure (7A**).** The depth level to groundwater (dynamic water) in Kirkuk Governorate for the period (2000-2025) ranges between 2 to 215 m. The areas with large depth levels to groundwater are represented in the areas of Qara Hanjir, Goldara, Shwan Junction, Qara Salem, Kirkuk city center, Sargaran, and southern Kirkuk, as shown in figure (7B) and figure (7C), the graphical chart for both depth to groundwater (static water and dynamic water). The level of dissolved solids in groundwater in Kirkuk Governorate for the period (2021-2025) ranges between 172 to 17411.84 mg/L, and the areas with high levels of dissolved solids in groundwater are represented in the Rashad and southern Kirkuk city areas towards the Hamrin structure, as shown in figure (7D) and figure (7E), the graphic chart of the concentration of dissolved solids in groundwater.

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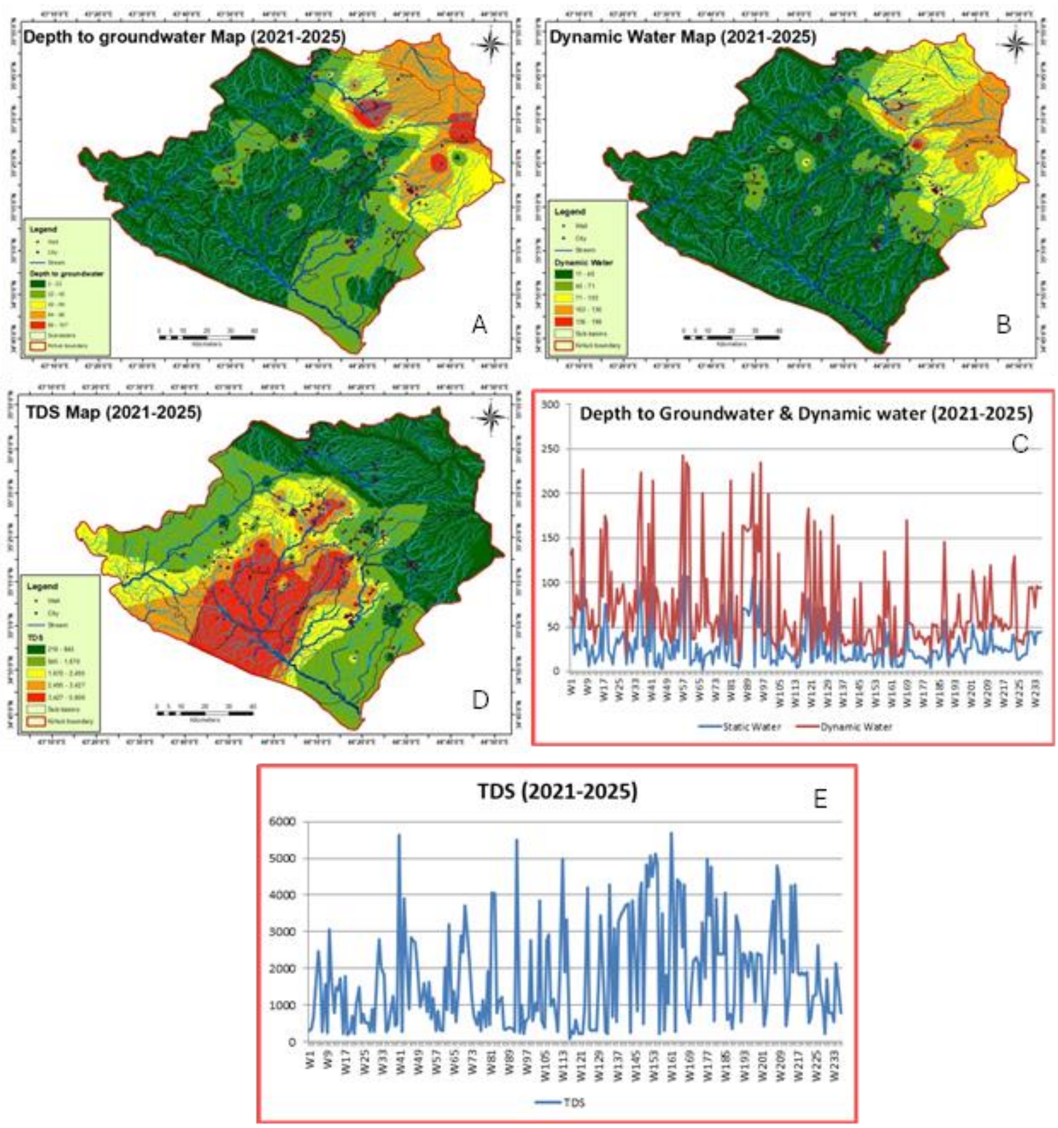

Fig. 6. Depth to groundwater maps and graphs (static, dynamic water and TDS) for the period (2021-2025)

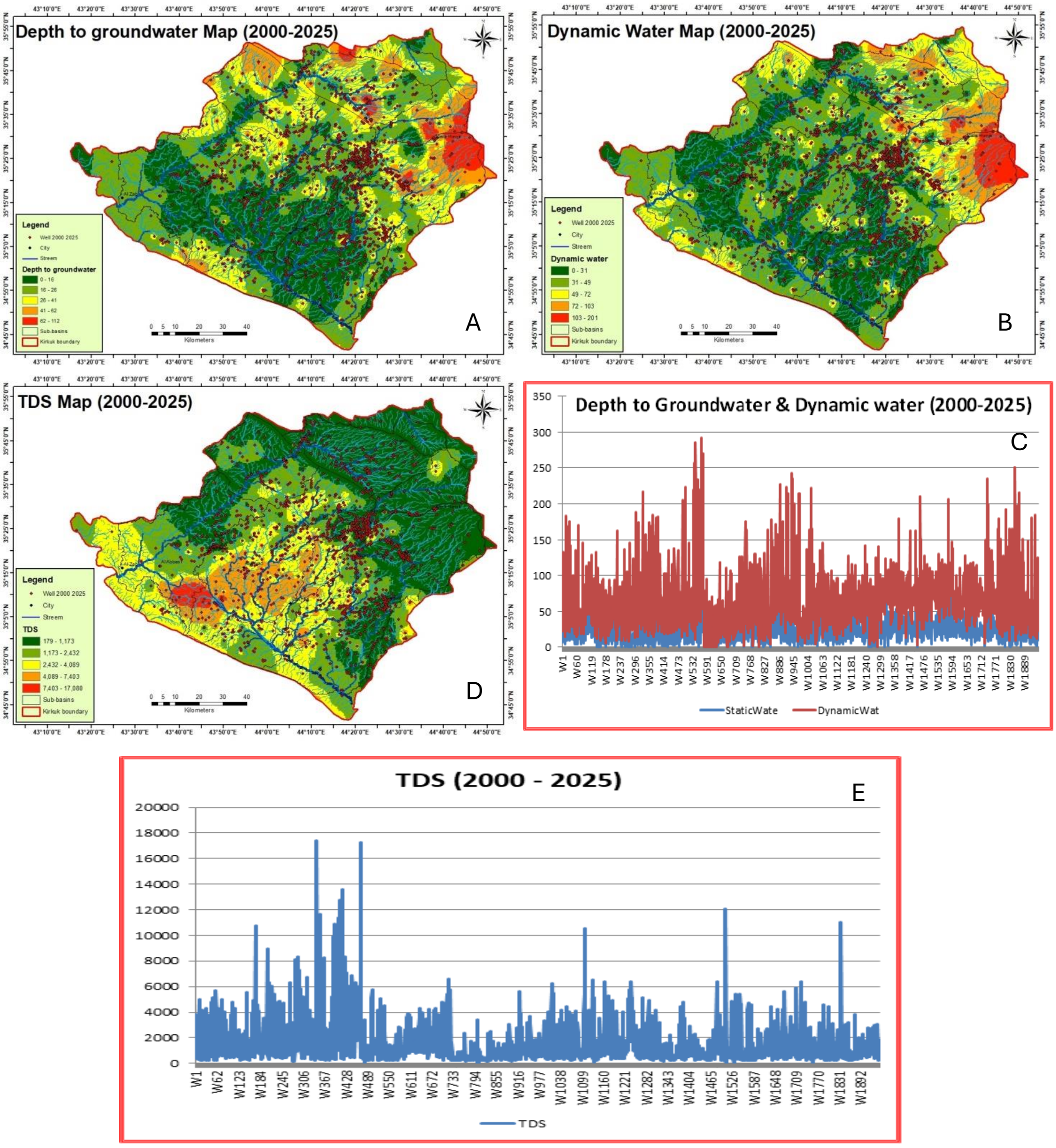

Fig. 7. Depth to groundwater maps and graphs (static, dynamic water and TDS) for the period (2000-2025)

Conclusions

The analysis of the results indicated negative trends between 2000 and 2025 in the groundwater level in the areas of Qara Hanjir, Goldara, Laylan, the Daquq district center and its surroundings, Rashad subdistrict, Mir Isfahan, Qara Salim, Shwan subdistrict center, and south of Kirkuk city towards Hamrin. The decline ranged between 52 and 90 meters in the areas of Qara Hanjir, Kuldareh, and Laylan, and between 55 and 105 meters in the areas of Daquq district center and its surroundings, Rashad subdistrict, Mir Isfahan, Qara Salim, Shwan subdistrict center, and south of Kirkuk city towards Hamrin. The groundwater level was found to fluctuate within a relatively narrow range of between 15 and 36 meters in the areas of Hawija and Dibis subdistricts, and between 18 and 40 meters in the areas north and northeast of Shwan subdistrict, Kirkuk city center, Taza Khurmatu subdistrict, and Riyadh and Abbasi subdistricts, respectively. It can be concluded from the maps and graphs that the depth of the groundwater level has decreased. It has increased over the past 25 years due to excessive irrigation withdrawals and declining rainfall. Therefore, changes in irrigation practices in the Daquq, Shawan, and Hawija areas are needed to achieve sustainable groundwater management.

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Recommendations

The study recommends the following:

1. A complete halt to the drilling of wells for agricultural use, as they deplete large quantities of groundwater, especially in the areas of Daquq District, Alton Kopri Subdistrict, Hawija District, Riyadh District, Abbasi District, and Dibis District.
2. A complete halt to the issuance of well-drilling licenses except in cases of extreme necessity to address water scarcity in residential areas and villages far from desalination projects. Such licenses should be granted exclusively by the Council of Ministers, given the importance of the issue.
3. Emphasize the need to remove violations of wells drilled by farmers and agriculturists, and impose heavy fines to prevent the random drilling of wells without the approval of official authorities.
4. Promote water harvesting projects in eligible areas, including the construction of small dams to store rainwater and utilize it for agriculture and irrigation, and to pipe water from these dams to nearby cities, residential neighborhoods, and villages to address water scarcity in those areas.
5. Conduct a comprehensive hydrological and hydrogeological study of Kirkuk Governorate to identify areas for the construction of small dams for water harvesting.

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