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SERVICES FOR SCIENCE AND EDUCATION

Impact of Climate Change on Erbil Groundwater Basins (North, Middle and South)

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ABSTRACT

The increasing global temperatures and change in precipitation forms due to the climate change have effect on Earth's hydrological systems, with significant impact on boundary of groundwater basins. This study provides the present understanding of the impact of climate change on Erbil groundwater basins, emphasizing the variable interactions between climatic variables and groundwater dynamics, the largest groundwater basin in the Middle East, the northern part of Iraq. The study presents how rising temperatures lead to lowering groundwater levels and impact Electrical conductivity (EC) in the study area. This has direct impacts on water resources and keeping sustainable groundwater management in the area. The study aims to determine the main factors that impact Erbil basin resources and propose appropriate solutions to keep these vital resources sustainable. In conclusion, this study presents the interaction between climate change and Erbil basins, determining the need for a best approach and techniques to address the challenges posed by these dynamic environmental changes. Effective water resource management, coupled with most appropriate strategies, is imperative for ensuring the resilience of groundwater systems in the face of ongoing and future climate variability.

Keywords: groundwater, climate change, Erbil basin, temperature, groundwater management

INTRODUCTION

With its profound effects on ecosystems and natural resources, climate change has emerged as one of the planet's most pressing issues in recent times due to human activities. Groundwater basins are the most important affected environmental components because they are vital freshwater reserves that sustain ecosystems, agriculture, and human populations. (Kumae, 2012; Costa et al., 2021). This study highlights the complex interactions between groundwater basins in the Erbil basin and climate change, emphasizing the varied effects of shifting climatic trends on these essential subterranean water reservoirs. One of the principal sources of water supply in the study region is groundwater, which is also used for agriculture and drinking. The hydrological cycle is dynamically altered by climate change, which also affects temperatures, precipitation patterns, and extreme weather events. (Hoarcek et al., 2008; Nanekely et al., 2019). The dynamics of groundwater recharge, storage, and outflow in the Erbil basin are thus

significantly impacted by these changes. One of the main repercussions of precipitation patterns is the changing of climatic patterns, which results in changes to the frequency, intensity, and distribution of rainfall. Aquifer replenishment is directly impacted by these changes, which in turn affects the sustainability and availability of groundwater resources. Reduced groundwater recharge causes groundwater levels to drop and competition for scarce water resources in the afflicted area to increase in long-term drought-stricken areas. Rising global temperatures, another hallmark of climate change, contribute to increased evaporation rates and exacerbate water scarcity in regions already grappling with aridity as the demand for groundwater outpaces its replenishment (Soundala and Saraphirom, 2022; Schulz et al., 2020). In addition to quantity, there is a close relationship between groundwater quality and climate fluctuations. Temperature and precipitation variations affect the movement and destiny of pollutants, changing the geochemical composition of groundwater (Taylor et al., 2013). Reduced streamflow, land subsidence, and heightened drought susceptibility are the results. Furthermore, excessive groundwater extraction can degrade water quality by encouraging the influx of contaminants into aquifers (Aladejana et al.,2020). The research area is characterized by dry or semi-arid regions; so, management is necessary to provide water consumption in the basin area. The area's groundwater recharge and evaporation rates are both high. (Azizi et al., 2021). The region is also known for having high surface water velocity and short duration, which can cause flooding (Fathy et al., 2021).

Rainfall is the primary source of aquifer system recharge in the studied area. Given that the demand for water rises as the population grows. Any region's climate and hydrogeological state are reflections of its natural characteristics, which have an immediate effect on the hydrological cycle. The water balance equation, often known as the continuity equation, is based on the mass conservation rule. Changes in storage are utilized to balance the difference between all input and output for any control volume and duration. The water balance program is used in this work to calculate the effects of intentional modifications to groundwater basins. (Al-Sudani, 2019). Erbil basin is divided into three main sub-basins which are: (Kapran, Central, and Bashtepa) sometimes called (Northern, Central and Southern). The rock of the study region consists of the (Upper Miocene – Recent) and mainly consists of Muqdadiya, Bai Hassan formations and Quaternary deposits (Hassan, 1998). While several previous studies calculated water balance for particular locations within the basin, these studies that are conducted in the Erbil area are the Hydrogeological Study of the Central sub-basin (Hassan, 1981), the study of the water balance of the central part of the Erbil basin (Al Kubaisi et al., 2019). Similarly, another study conducted on the Erbil basin groundwater recharge potential zone using the fuzzy-analytical Hierarchy Process (AHP) in the northern part of Iraq (Hamad, 2022). The management of groundwater resources in the Erbil basin is beset with numerous issues. The basin's water levels dropped, necessitating a deeper comprehension of the climate's effects on the research region and the identification of the best course of action for further studies in this area.

By examining the existing level of knowledge, pointing out knowledge gaps, and suggesting future directions for research and sustainable water resource management in the face of climate change, this study seeks to highlight the complexity of this relationship.

MATERIALS AND METHODS

Description of the Study Area

Erbil basin is located in northern part of Iraq, and it is bounded by two rivers known as Greater Zab and Lesser Zab Rivers on the north-west and south-east sides. The basin is divided into three main sub-basins: KAPRAN, CENTRAL, and BASHTEPA. The total area of the basins area about 3,200 km2 (Hassan, 1981; Hassan, 1998). The geographical position of the basin is located between longitude (E) of 44.00°, and latitude (N) of 36.19 ° with an elevation of about 420 m a.s.l. In addition, the region's climate has been classified as arid and semi-arid. The location of the basin is presented in Fig. 1.

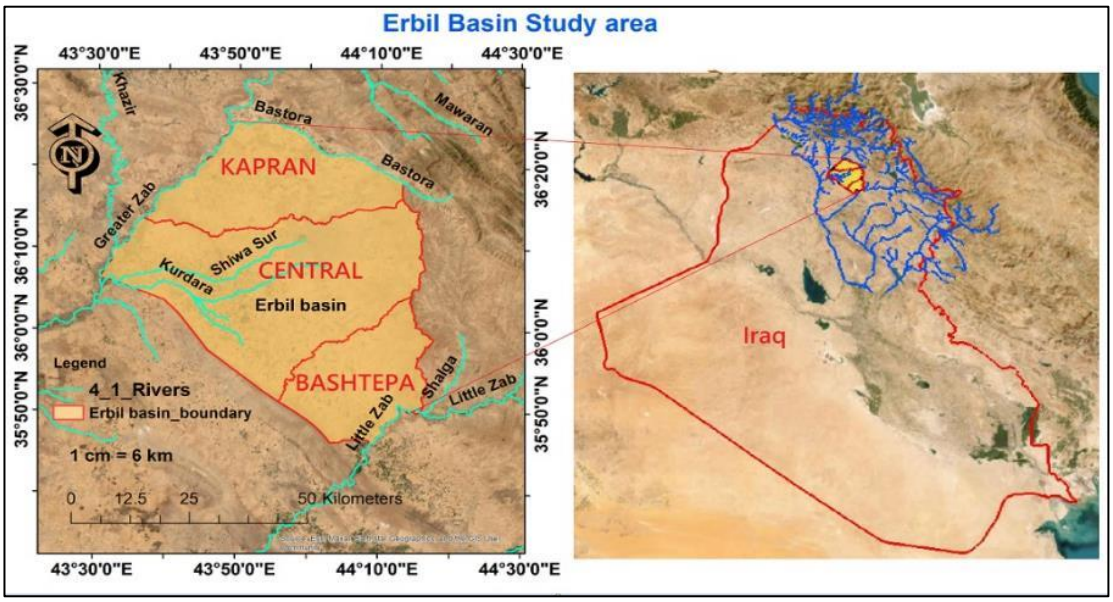


Figure 1: The map of the study area location (Erbil basin)

Climate Condition:

Erbil basin, is the largest groundwater basin in the middle east, which is in the Kurdistan Region of Iraq. The climate of the Erbil plain is classified as a semi-arid region, featuring hot summers and cool winters. The following information is the characteristics of the Erbil area's climate, obtained from Erbil meteorological station Ministry of Transport and Communications for the period (1995-2020) but the data analysis to get the average monthly values described in Table 1.

Table 1: The climate data recorded in Erbil station for the periods (1995-2020)

Erbil station data during (1995-2020)						
Month	**Winspeed m/s**	**Sunshine hr/day**	**Rainfall mm**	**Relative Humidity%**	**Evaporation (mm)**	**Avg. Temp Č**
Oct	1.92	7.86	18.61	42.18	194.18	21.09
Nov	1.71	6.50	36.92	57.72	94.73	13.50
Dec	1.83	5.19	67.63	67.70	56.22	8.47
Jan	1.97	4.91	74.27	72.39	50.70	6.95
Feb	2.20	5.81	63.13	67.23	68.45	8.20

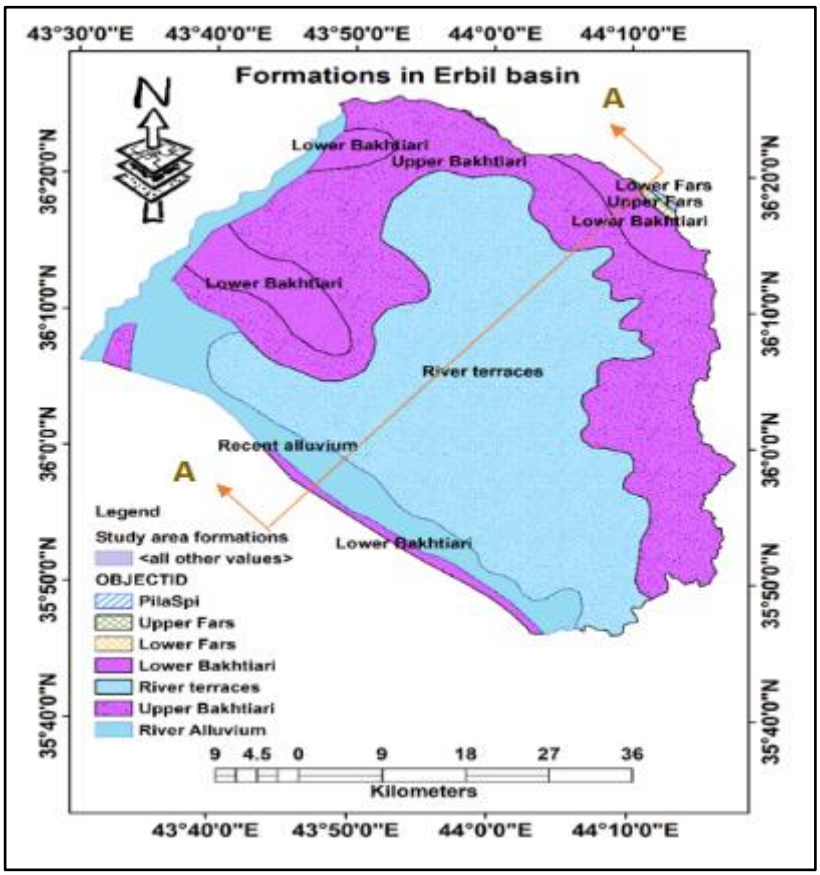
Mar	2.37	6.57	70.88	60.69	120.09	11.97
Apr	2.36	7.49	45.68	54.30	162.71	16.78
May	2.36	9.31	13.27	38.90	280.16	22.76
Jun	2.23	11.52	1.62	27.59	371.26	28.53
Jul	2.08	11.66	0.20	25.71	419.11	31.57
Aug	1.84	11.21	0.04	27.62	297.82	31.02
Sep	1.71	10.12	2.41	31.75	292.10	26.40
Sum	24.60	98.15	394.65	573.79	2407.53	227.24
Avg.	2.05	8.18	32.89	47.82	200.63	18.94

The above table includes the average and annual values of the climate conditions estimated during (1995-2020): the sum of the Rainfall is 394.65mm, the Evapotranspiration is 2407.53 mm, Windspeed is 24.60 m/s, Sunshine is 98.15hr/day, Relative humidity is 573.8 % and Average temperature is 18.94 C̊ respectively.

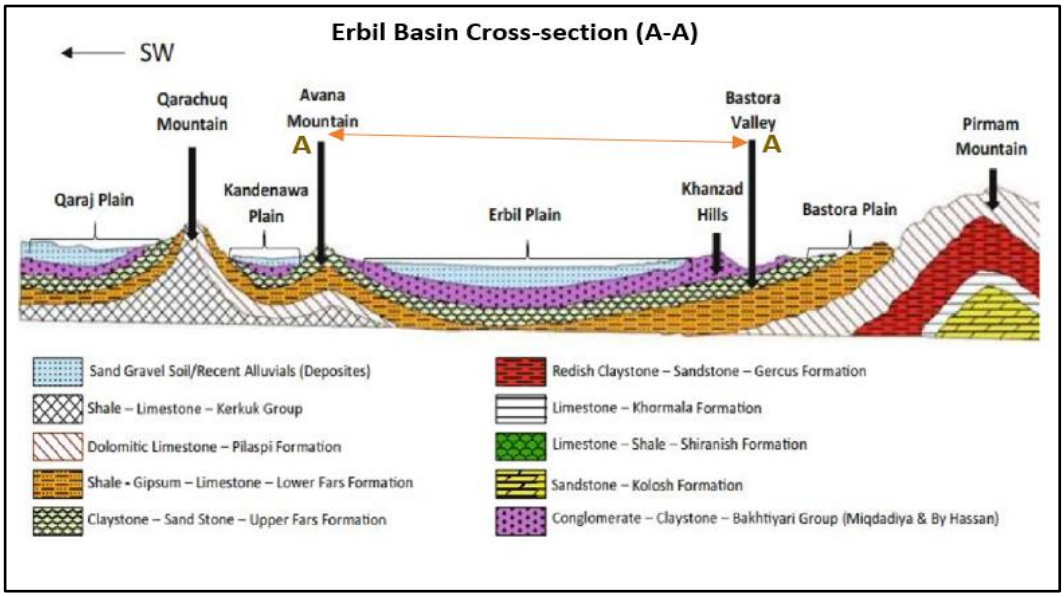
Variations in temperature have a significant impact on agriculture, the population, and the environment. The policies of neighboring countries might worsen water scarcity by diminishing water sources and flooding river routes. Both human activity and local ecosystems may be impacted by such variations in water flow. Together, governments, local communities, and international organizations must create plans and regulations that address the effects of climate change and guarantee the sustainable use of water resources.

Hydrogeological Conditions of Erbil Basin:

The Greater Zab River forms the basin's northwest boundary; the Lesser Zab River forms the basin's southeast boundary; the Kirkuk Anticline forms the basin's southwest boundary; and the beginning of the High Folded Zone forms the basin's northeastern boundary on the highs where the Pila-Spi Formation outcrops (Al Mewan Anticline; Pirmam Anticline). (Shekhmamundy and Surdashy, 2022). The Erbil Basin's Aquifer System receives an estimated average of precipitation annually, and groundwater normally flows from the upstream mountainous area towards the Greater Zab River, which is generally considered a discharge area. The study area's geological map is shown in Fig. 2.



(a)



(b)

Figure 2: The geological map of the study area (a) Geological formations of the study area created by [ArcMap 10.8] and (b) Cross section (A-A) modified after (Shekhmamundy and Surdashy, 2022).

Moreover, Erbil Plain is situated in the low folded zone as well. The region is bordered by the Bastora stream in the north, the Pirmam Anticline in the south, and the Demir Anticline in the south, which borders the Shamamk plain. As a result, the Greater Zab River borders the region to the west and Shalghah Bestana and the Lesser Zab River to the east. (Shekhmamundy and Surdashy, 2022). Table 2. Shows the geological formations are composed.

Table 2: Geological formations of the Erbil region (Shekhmamundy and Surdashy, 2022).

No.	Formation types	Formation's composition
1	Quaternary Deposits	Rock Fragments, Gravelly, Silty, Sandy
2	Upper Bakhtiari (Bai Hassan)	Conglomerate, Sandstone, Claystone
3	Lower Bakhtiari (Mukdadiyah)	Pebbly Sandstone, Siltstone, Claystone
4	Upper Fars (Injana)	Sandstone, Siltstone, Claystone
5	Lower Fars (Fatha)	Gypsum, Marl Limestone, Siltstone, Claystone
6	Pilaspi	Well Bedded Limestone
7	Gercus	Sandstone, Siltstone, Claystone

IMPACT OF CLIMATE CHANGE ON ERBIL BASIN

Groundwater resources are greatly and multifariously impacted by climate change, which affects recharge, storage, and quality (Nanekely et al., 2019). The groundwater supplies in the Erbil basin are impacted by climate change in the following ways:

Altered Precipitation Patterns

The volume and rate of groundwater recharge are impacted by changes in precipitation patterns, which include altered timing, intensity, and distribution of rainfall. Reduced or erratic rain can also result in decreased groundwater recharge, which can impact aquifer replenishment and contribute to declining groundwater levels (Kumar, 2012).

Increased Temperature

Temperature increases have the potential to accelerate surface water evaporation rates and raise total water consumption. Increased evaporation of water due to higher temperatures might exacerbate water stress and decrease groundwater availability (Nanekely et al., 2019). The climatic data graphic is presented in Fig. 3.

The relation between temperature and evaporation is seen in Fig. 3. It demonstrates how rising temperatures at the meteorological station in Erbil might result in greater rates of evaporation, surface runoff, wind speeds, and sunshine. The precise consequences, however, will vary depending on a number of variables, such as the surrounding environment and topography. It's critical to remember that these modifications are a part of a larger, intricate system, and that their effects may differ depending on the location and environment.

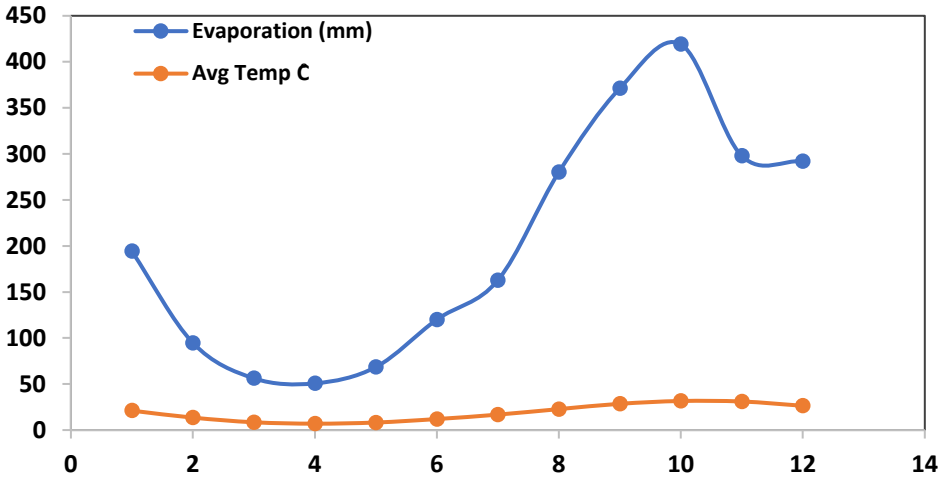


Figure 3: Change in temperature with increased evaporation between (1995-2020).

Changes in Land Use

Changes in land cover can result in increased runoff, which lowers the amount of water that infiltrates the ground and recharges aquifers. For more information about the land use in the study area, see. Altered climate conditions can influence vegetation patterns and land use, affecting water infiltration rates and groundwater recharge, see Figs. 4 and 5

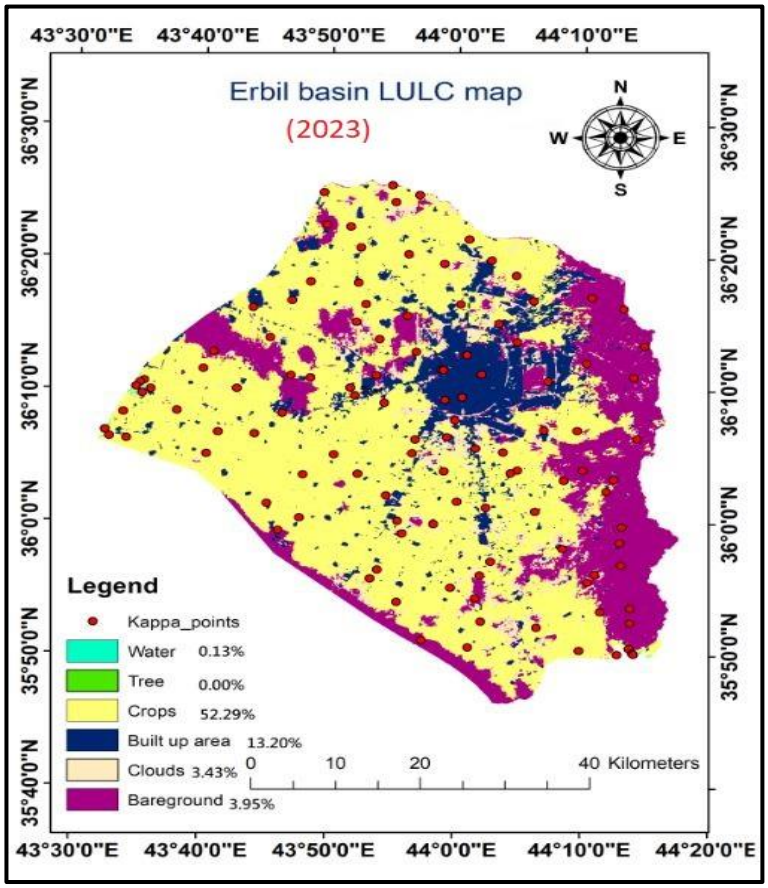


Figure 4: Land use Land cover map created by Arc Map 10.8.



Figure 5: Development of Erbil City between previous and present.

Groundwater in the Erbil basin may be significantly impacted by increasing Erbil city's density, growing its construction area, and reducing its green space in the recharge zones of the Mala Omer and Kasnazan regions. Concrete and other large impermeable surfaces are frequently used in the construction of infrastructure and structures. Because of these impermeable surfaces, less rainwater naturally seeps into the earth, reducing groundwater recharge. Less water is therefore able to seep into the aquifers that supply the groundwater system, see Fig. 6.

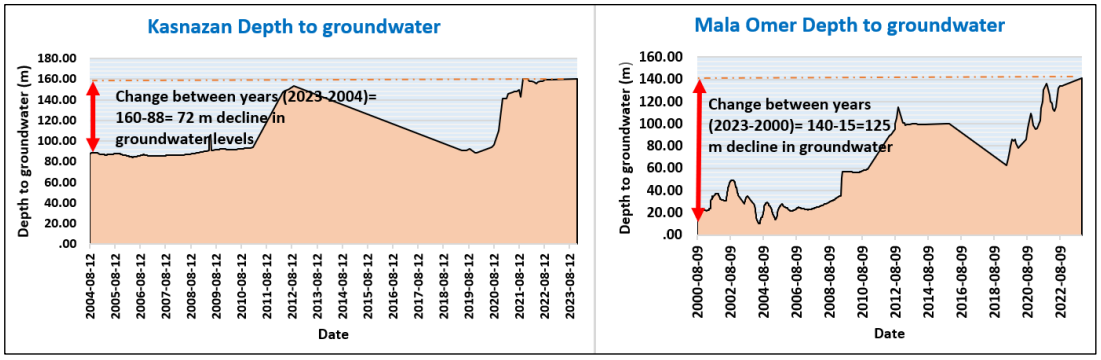


Figure 6: Decline of Groundwater levels between (2000-2023) in Kasnazan and Mala Omer wells

The groundwater level reduction in the Mala Omer and Kasnazan recharge zones is depicted in Fig. 6. Because of this, the groundwater depths at Kasnazan and Mala Omer differ by (72 and 125) meters, respectively. These result from increased building area and density in the recharge area, which can disrupt the hydrological cycle naturally and lower groundwater levels in the Erbil basin. Furthermore, it has significant effects on the rates of infiltration and recharging of the Erbil groundwater basin. Since land surfaces are frequently altered during building, there are more impermeable regions overall. This decreases the amount of rainwater that naturally seeps into the earth, replenishing the groundwater basin. The total recharge of groundwater may consequently decline.

Groundwater Quality

Contaminants from construction materials, runoff, and other sources are frequently introduced by urban growth. The Erbil basin's Electrical conductivity (EC) is one example of how rising pollutant concentrations in the residual groundwater have a detrimental effect on water quality when groundwater levels fall. Variations in temperature and precipitation patterns impact the movement of pollutants, which in turn impacts the quality of groundwater. Variations in groundwater quality could have an effect on ecosystems that depend on dependable, clean groundwater as well as human health and agriculture. According to (Kumar, 2012), The Intergovernmental Panel on Climate Change (IPCC) projects that over the next century, the global mean surface temperature will rise by two to four degrees Celsius, with an estimated increase of 0.6 ± 0.2 oC since 1861. The effect of temperature on the groundwater resources in the Erbil basin EC was the main topic of this investigation.

Data Collection and Fieldwork:

The Data of this study was obtained from different places and Directorates:

- General Directorate of Meteorology and Seismology.
- Directorate of Erbil Groundwater.
- Directorate of Erbil surrounding water.
- Field measurements and office work .
- Erbil Environment organization.

Moreover, data collection and sampling of groundwater wells to evaluate EC and temperature are essential for understanding an aquifer system's hydrological characteristics.



Figure 7: Data collection and Field sampling

In this methodology, 47 samples of different wells have been selected to evaluate the temperature and EC of the Erbil basin. In the field, the temperature was measured by a temperature instrument after assessing the well temperature condition and recording. Subsequently, the EC is calculated by (EUTECH) instrument (CON 510) type. See Fig. 7.
The tabular data includes each well's coordinates as well as its temperature and electrical conductivity (EC). A thorough understanding of groundwater quality and hydrodynamics is aided by the gathered data and any field observations, which helps with well-informed decision-making for the management of water resources and environmental preservation.
See Table 3;

Table 3: The Data of wells within the Erbil basin

ID	Wells Names	Longitude	Latitude	Elevation (m)	Temperature (˚C)	EC µm/cm
1	Kasnazan	421958.08	4006819.58	589.70	20.20	510
2	Gullan	415315.53	4006575.20	451.40	24.80	512
3	Abasseia	379669.47	3998776.85	261.70	22.30	840
4	Tarjan	388381.45	3998129.44	293.40	22.80	785
5	Satoor	391871.43	4004654.73	431.30	24.20	907
6	Sebiran	402125.71	4012025.66	376.30	19.80	805
7	Jadida Zab	391058.03	4016987.56	318.30	22.60	544
8	Kawraban	389542.29	4009585.38	417.40	24.50	609
9	Khabat	380287.77	4015038.01	286.70	22.90	796
10	Chalugi Gchka	383464.63	4013201.75	346.50	22.70	701
11	Kawrgosk/1	391725.12	4023473.29	292.40	22.80	622
12	Grda Chal	404224.93	4024296.50	387.00	22.90	624
13	Qafar	407708.31	4028059.77	436.10	23.10	540
14	Shawis	417588.42	4012223.97	511.50	21.60	554
15	Qultapa Yaba	412816.16	3979753.68	382.10	22.50	768
16	Hamza Kor	416389.55	3980455.41	413.90	21.50	750
17	Grd Mala	415049.57	3985171.18	413.50	20.20	638
18	Kardiz	419607.77	3983575.70	446.10	19.50	477
19	Azyiana	427599.44	3974850.10	439.40	21.80	702
20	Lajan	427156.94	3990395.69	643.70	20.70	535
21	Daratoo	412115.00	3995104.56	414.60	22.10	542
22	Grdarasha	412563.37	3998604.60	411.40	22.30	621
23	Baghi Shar	411174.30	4005306.46	408.50	22.90	744
24	Glkand	410708.77	4004656.12	404.00	24.10	538
25	Qoritan	405404.49	3993252.88	358.50	23.80	885
26	Tandora	395414.40	3993026.87	313.00	22.60	975
27	Grd Azaban	394913.97	3985199.97	308.90	25.70	1100
28	Qurshaghu Old	402865.12	3975893.80	337.10	26.10	1345
29	Pirdawd Old	403054.35	3986931.47	341.20	22.30	670
30	Shawes	416042.00	4011550.00	493.00	22.00	532
31	Berkoty Kon	414016.00	4009826.00	458.00	23.70	492

32	Dolabakra	416507.03	3972788.05	360.00	22.30	743
33	Grdasor	424685.00	3967936.02	322.00	22.70	535
34	Poreja No.2	423243.00	3976387.00	416.00	22.80	755
35	Mirakan Xdr	428341.00	3984110.00	536.00	21.60	803
36	Dolaza Mustafa	413401.00	3974145.00	352.00	21.30	738
37	Du Shiwan	428452.00	3981682.00	540.00	20.40	605
38	Sheakhanan Bchok	417530.00	3964914.00	292.00	22.30	732
39	Sorbash Xdr Badil	406063.00	3975332.00	346.00	23.20	766
40	Dukala2	406557.00	3977009.00	352.00	22.60	748
41	Elnjakh Badil1	420477.00	3979466.00	433.00	21.40	680
42	Sebiran Axa Badil1	398196.00	3977526.00	334.00	23.40	835
43	Qushtapa 39	413396.00	3982143.00	403.00	21.40	673
44	Qazixana Badil 1	408703.00	3973976.00	338.00	23.20	745
45	Kani Bzra	422643.00	3985422.00	537.00	21.20	548
46	Plnga Badil 1	407183.00	3984972.00	382.00	22.40	636
47	Grdasor Badi 1	423044.00	3971704.00	374.00	21.60	640

Furthermore, producing maps of EC in the Erbil basin using Inverse Distance Weighting (IDW) and Kriging offers important geographical insights into the distribution of this crucial parameter (Mustafa and Mawlood,2023). The map of the current works was compared with previously acquired data from 1998 in order to evaluate the EC values (Al Sallag, 2001).

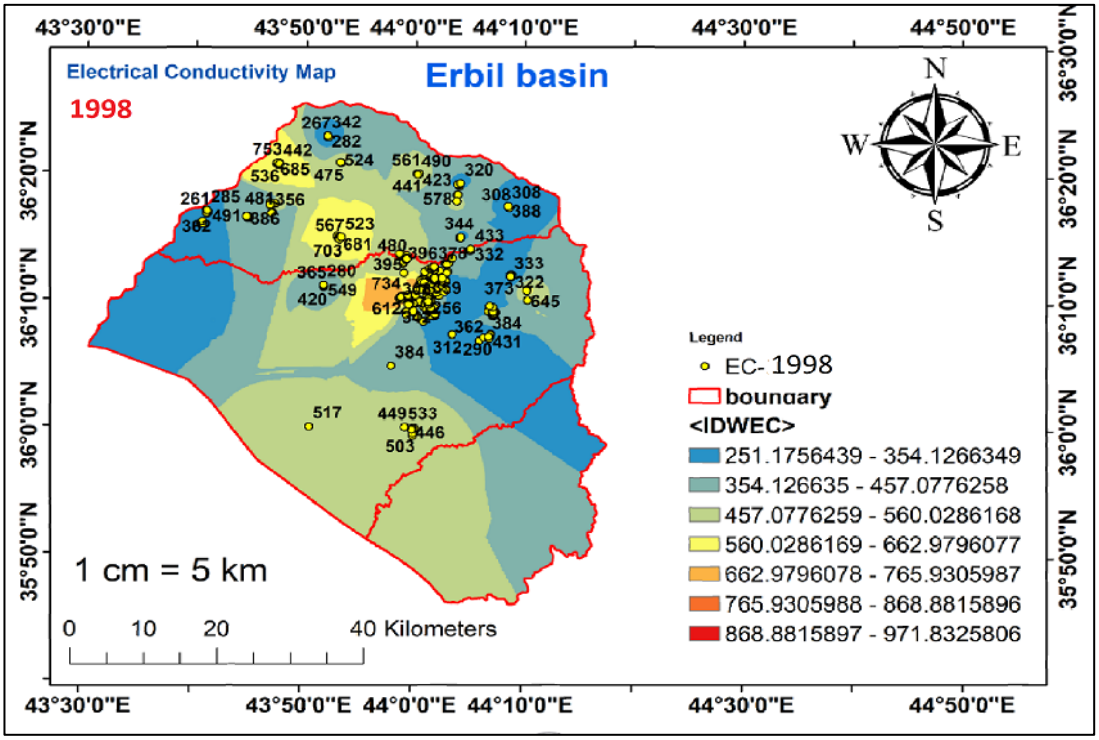


Figure 8: The Electrical conductivity map using the IDW Interpolation method (Arc Map 10.8) in (1998)

Through the incorporation of geostatistical techniques into the examination of groundwater characteristics, policymakers can augment their comprehension of subterranean processes and devise more focused approaches for the sustainable management of water resources. Refer to Figs. 8–13.

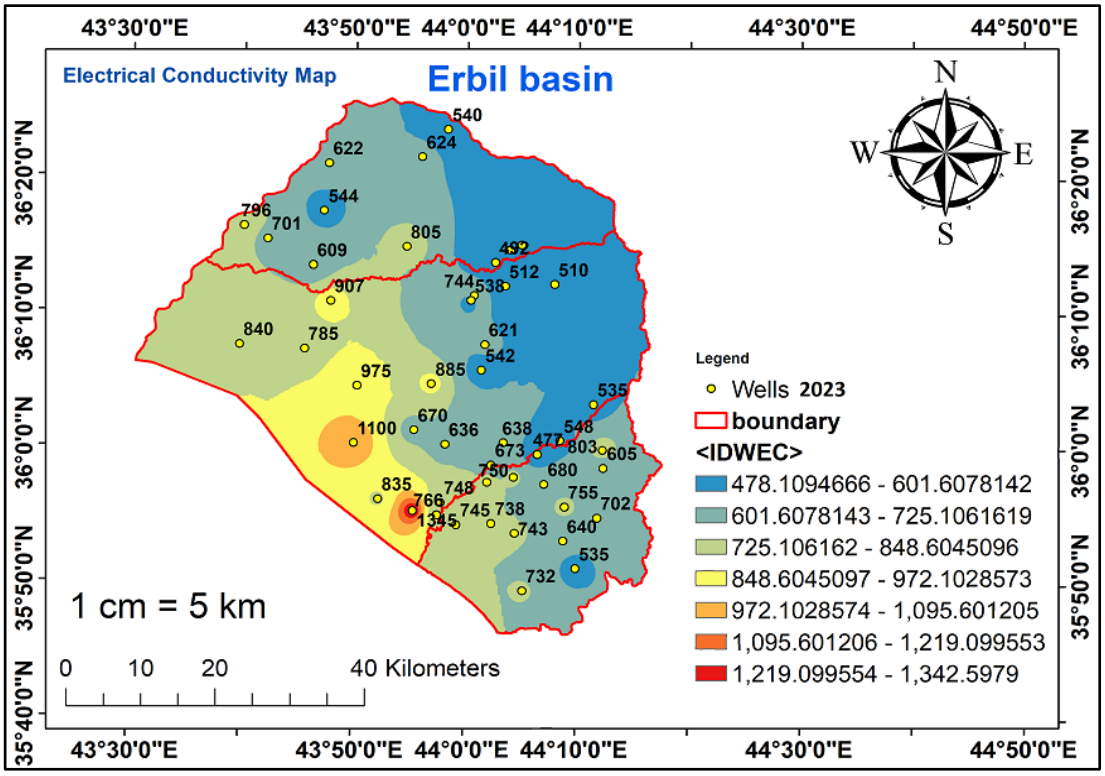


Figure 9: The Electrical conductivity map using the IDW Interpolation method (Arc Map 10.8) in (2023)

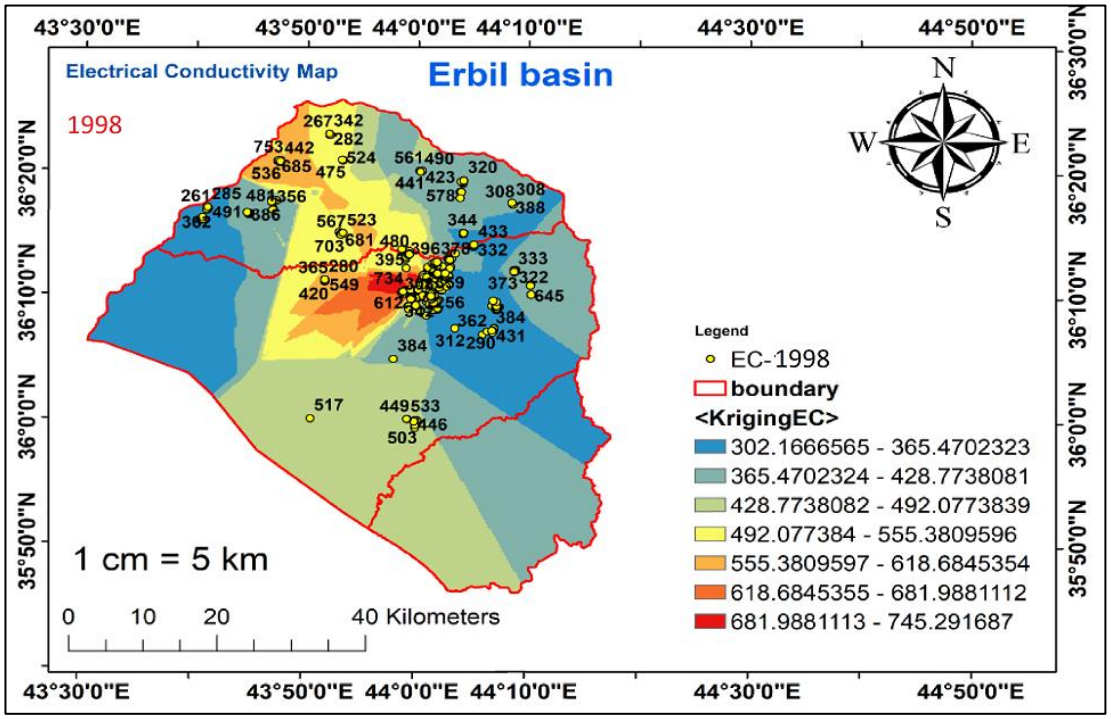


Figure 10: The Electrical conductivity map using the Kriging Interpolation method (Arc Map 10.8) in (1998)

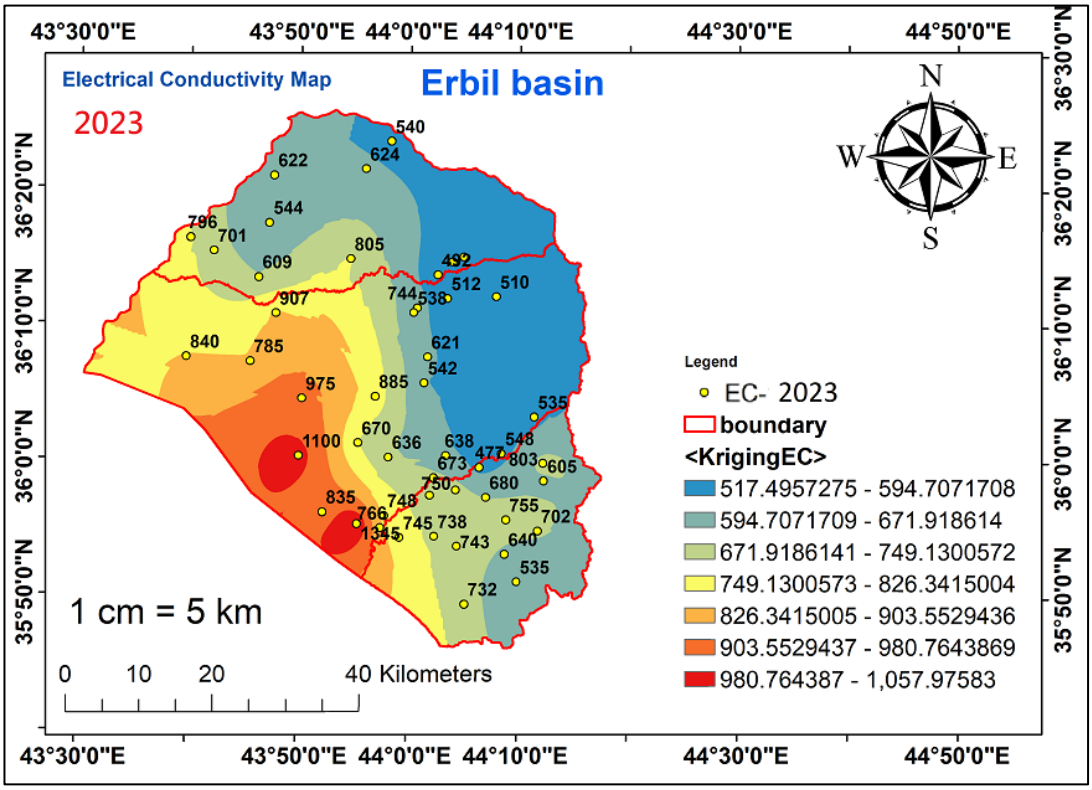


Figure 11: The Electrical conductivity map using the Kriging Interpolation method (Arc Map 10.8) in (2023)

Moreover, the Analysis of the obtained well temperature is also mapped by IDW and Kriging methods as Fig. 12.

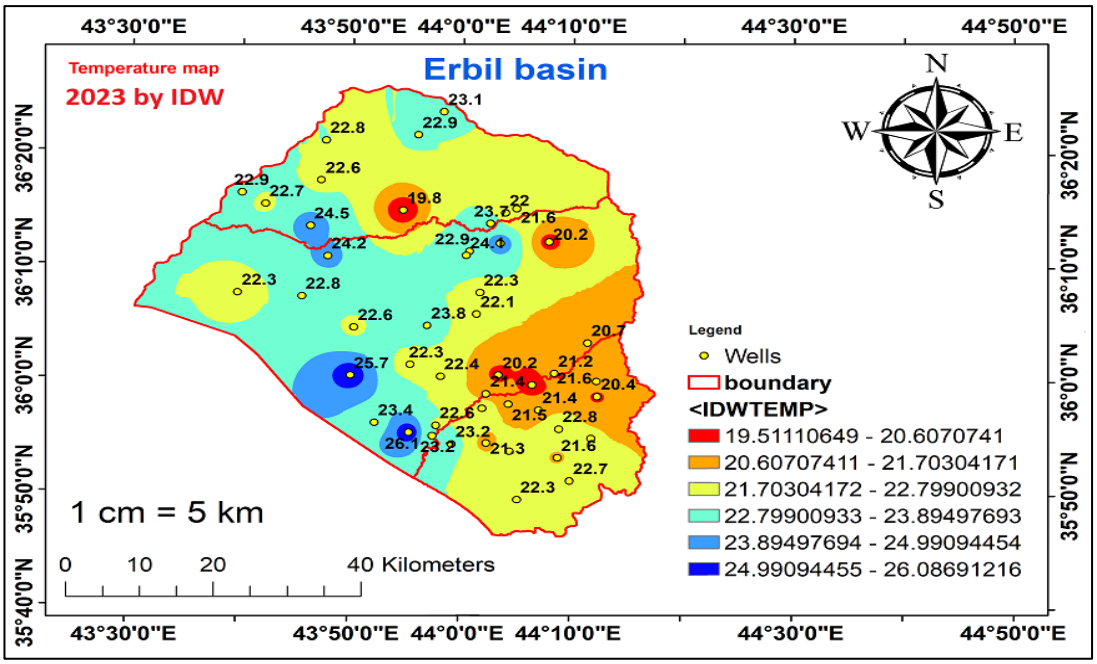


Figure 12: The Temperature map using the IDW method (Arc Map 10.8)

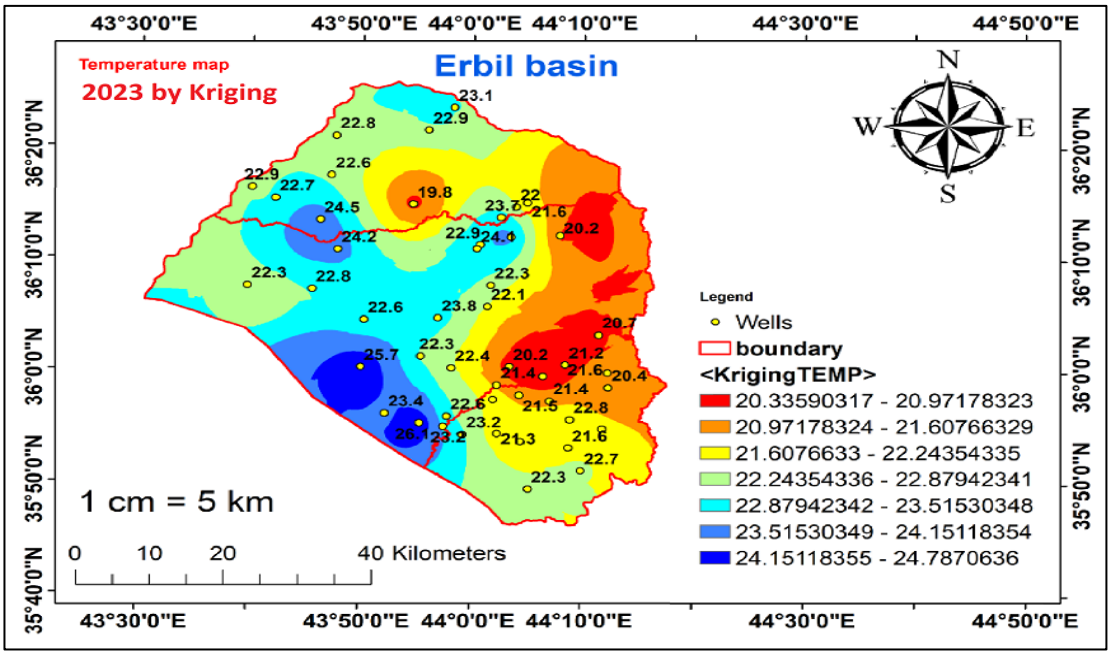


Figure 13: The Temperature map using the Kriging Interpolation method (Arc Map 10.8)

To evaluate changes in groundwater quality and comprehend the dynamics of hydrological systems, it is essential to compare metrics related to groundwater quality, such as temperature and Electrical Conductivity (EC), over time. A thorough examination of the Erbil groundwater

basin entails the use of interpolation techniques to produce maps that illustrate the temperature and EC distribution in space for the years 1998 and 2023. The objective of this study is to provide a nuanced understanding of the evolution of these groundwater parameters during the specified time period by employing both kriging and Inverse Distance Weighting (IDW) interpolation methods. IDW's simplicity and effectiveness allow it to quickly present an overview of geographical trends by giving weights to observed data according to how close together they are. However, as a geostatistical technique, kriging captures the intricate variability in the groundwater parameters by incorporating spatial autocorrelation (Mustafa and Mawlood, 2023). In order to identify trends and potential sources of variation, as well as to inform sustainable groundwater management strategies, a more thorough assessment of changes in EC and temperature patterns in the Erbil groundwater basin will be possible thanks to the comparative maps produced by IDW and kriging. For the protection and best use of the region's groundwater resources, this integrated approach promotes evidence-based decision-making and enables a thorough understanding of the hydrogeological dynamics.

$$Z(S_o)^N = \sum_{i=1}^{N} \lambda Z(S_i) \quad (1)$$

where:

- Z(Si) is the measured value at the i^{th} location
- λ_i = an unknown weight for the measured value at the i^{th} location
- S_0 = the prediction location
- N = the number of measured values

The physical and chemical characteristics of the groundwater system in the Erbil basin can be affected by temperature rise and changes in the electrical conductivity (EC), among other effects. The temperature fluctuates between 19 and 26 C. The following are some effects of temperature on Erbil groundwater: The study region's (EC) varies from 477 to 1345 µm/cm; however, in 1998, the values were lower and less than these ranges, coming in at 215 to 1003 µm/cm, which is lower when compared to the current data. See **Table 3** to compare the findings of this investigation with those of other research conducted in the same area;

Table 3: Compare this study values and previous studies

Water quality parameters	**EC µm/cm**			**Temperature C̊**				
Author names	min	max	avg.	min	max	avg.	Year	Study area
El-sallag, 2001	215	1425	448.34	……	……	……	1998	Erbil basin
Toma et al., 2013	260	620	…..	……	……	……	2013	Erbil city
Hamed et al, 2022	346	882	……	21	23	21.7	2020	Central part
Othman &Ibrahim, 2021	306	1421	……	……	……	……	2021	Erbil plain
Mustafa et al ,2021	124	977	……	……	……	……	2021	Erbil city
Hawez et al., 2020	265	1940	…..	16	24.7	…..	2020	Erbil province
Hamed, 2023	316	1051	……	……	……	……	2023	Shamamk
current study	477	1345	698.82	19.5	26.1	22.4	2023	Erbil basin
WHO, 2017	500	1500					2017	Standard

Table 3 shows that because of rising human activity and fast population expansion, the values of EC in 1998 are lower than those in 2023. This will result in more groundwater abstraction to meet demand and lower groundwater levels overall, particularly in the central sub-basin. There is a greater chance of major effects on groundwater quality, which could result in water contamination, if temperature and (EC) values rise in the Erbil basin. Temperature increases brought on by climate change can have an impact on groundwater recharge rates, precipitation patterns, and hydrological cycles.

Groundwater and Climate Changes:

Erbil basin in 1980 was divided into three main sub-basins with the known as; north, middle and south basins, in some studies it is called Kapran, Central and Bashtepa sub-basins with a total area of about 3,200 km2 (Mustafa and Mawlood, 2023; Hassan, 1998). Accordingly, the total area of the Erbil basin is estimated at approximately 3,100 Km2 the area of each basin is calculated by Arc Map 10.8, and the boundary of each basin gives the area below:

- North (or Kapran) sub-basin area=772 Km^2
- Middle (or Central) sub-basin area=1,742 Km^2
- South (or Bashtepa) sub-basin area=585 Km^2

Additionally, when new wells are drilled, the number of recorded wells rises with time. However, it should be noted that, according to statistics from the Directorate of Erbil Groundwater, there are currently more wells than there are recorded wells because of illegal wells.

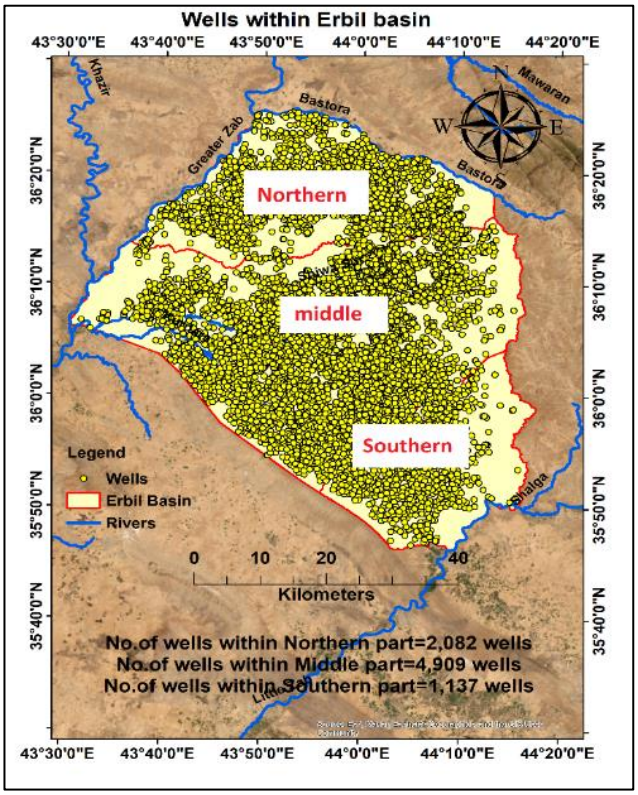


Figure 14: Map of the cluster of wells within the Erbil basin

As a result, a database for the groundwater archived data must be created. Arc Map 10.8 shows the locations of the current wells. see Fig. 14.

Fig. 14 shows that the number of existing wells within each sub-basis of Northern, Middle and Southern is (2,082-4,909 and 1,137) wells respectively, which is a good indicator of rapid population growth and urbanization within the selected region and also refers to change climate condition in the area. This study looks into how the Erbil groundwater basin's groundwater levels are affected by the rising water demand brought on by an increasing population density. To accommodate these increasing demands, widespread groundwater abstraction has now become the norm. (Nanekely et al., 2019; Khayyat et al., 2020; Hamd et al., 2023). The purpose of this study is to measure the degree to which higher population densities cause groundwater abstraction to rise and subsequently groundwater level falls. The recharging of aquifers in the Erbil basin is probably greatly aided by the recharge area of the Kasnazan and Mala Omer districts. See Fig. 15.

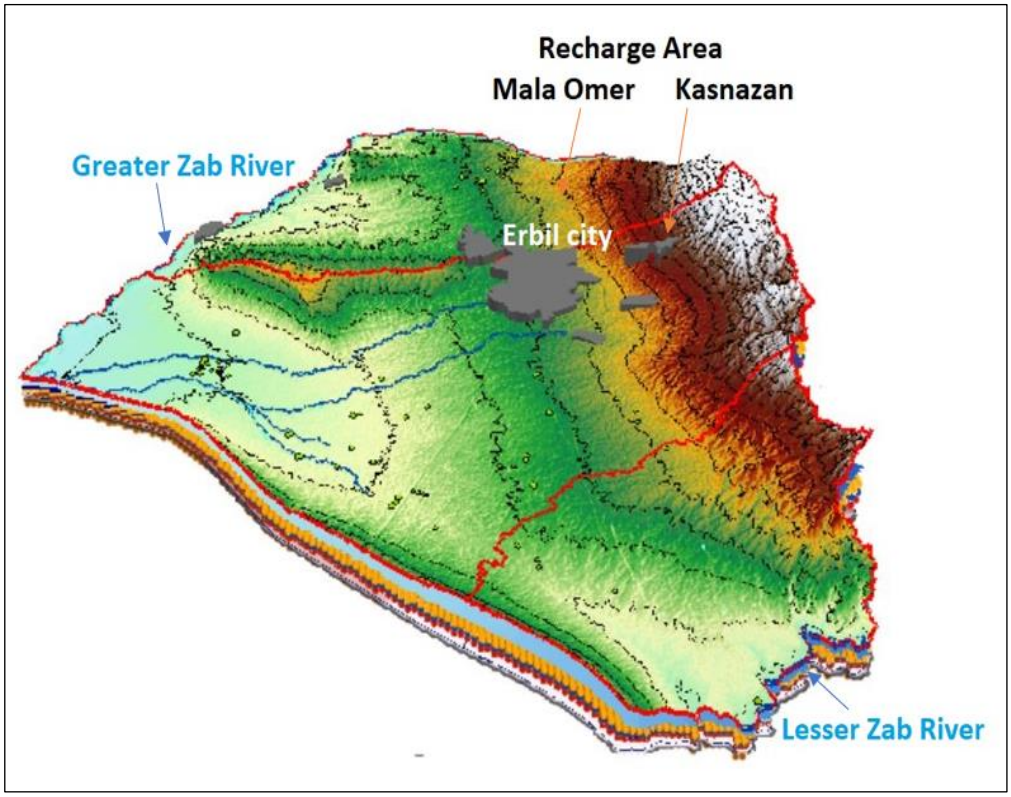


Fig. 15: Map of recharge area Kasnazan and mala Omer [Arc Scene, 10.8]

In the recharge zones, higher building densities may result in over-extraction of groundwater for diverse urban uses. Aquifers can be depleted by over-extraction, which can lower groundwater levels and have long-term effects on the availability of water.

Groundwater Recharge Depletion

Similar to many other places in the world, the Erbil groundwater basin is seeing changes in its climate, which are manifested in rising temperatures, changed precipitation patterns, and

erratic weather. The groundwater basin is already more vulnerable to drought conditions as a result of these climate changes. The Erbil aquifers are becoming less refilled as a result of the extended and intense dry spells and higher evaporation rates brought on by the warmer weather. As a result, the basin's groundwater levels are stressed, which raises the possibility of depletion (Nanekely et al., 2019; Mustafa and Mawlood, 2023). Based on information collected from the General Directorate of Water Resources and the Directorate of Erbil Groundwater, the amount of groundwater decrease in Erbil's three sub-basins is computed; Table 4 shows the results.

Table 4: Groundwater decline during (2004-2022) in Erbil's three sub-basins

Sub-basin Names	2004-2023	Area of sub-basins (m^2)
Northern (Kapran)	-33	772,000,000
Middle (Central)	-51	1,742,000,000
Southern (Bashtepa)	-55	585,000,000
Average decline	-46.3	(-) the negative sign means a decline
decline per 18 years	-2.57	in groundwater levels

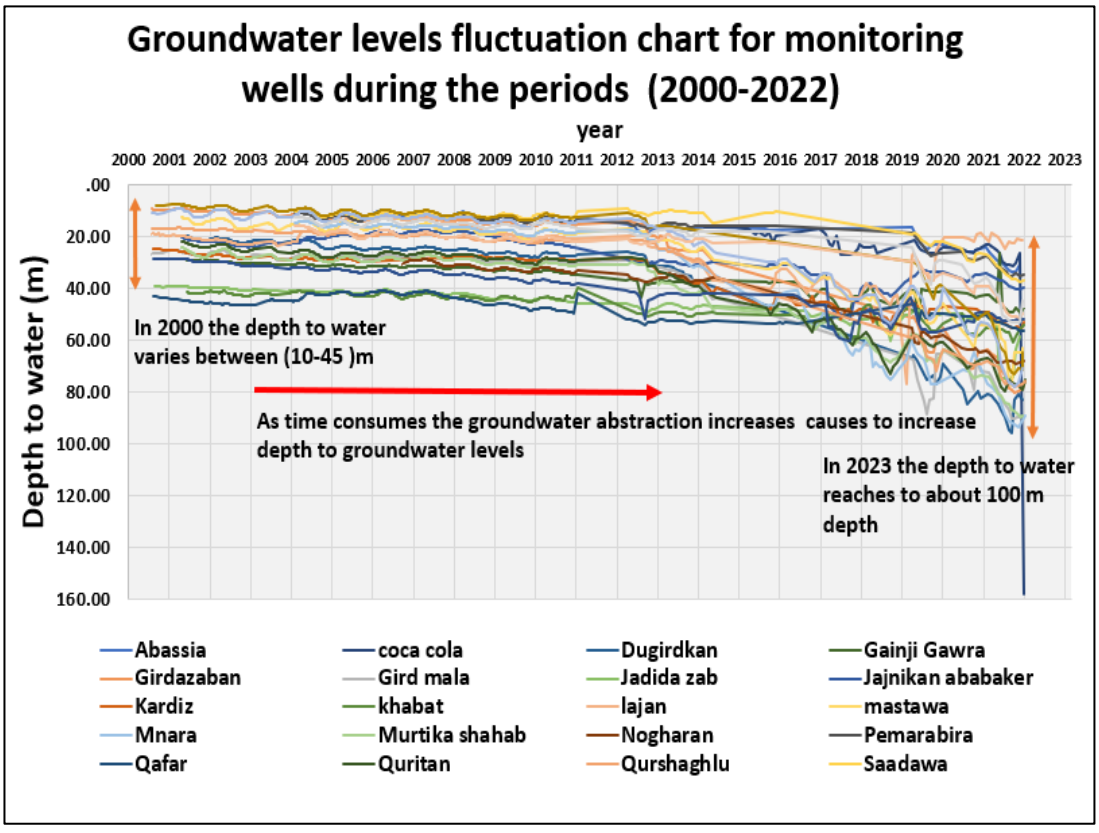


Figure 16: Groundwater fluctuation chart between years (2000-2022)

Table 3 shows that the three sub-basins of Kapran, Central, and Bashtepa have average declines in groundwater levels of (33, 51, and 55) meters, respectively. This decrease is based on the data from the 55 wells that the Erbil Groundwater Directorate uses to monitor groundwater depth on a monthly basis. The groundwater level reduction was calculated to be 2.57 m per 18

years. The unchecked drilling of wells within the Erbil aquifers is the primary cause of this groundwater loss. Thus, when more water wells are drilled, the Erbil groundwater is subjected to harsher circumstances, which results in a decrease in groundwater capacity and efficiency. Plotting of groundwater fluctuation is done over the years 2000–2023, and chosen monitoring wells provide data on groundwater depth, see Fig. 16.

Fig. 16 shows that the rate of decline accelerated after 2010, pointing to both inadequate groundwater management and rising water demand due to population development. Thus, the population growth and immigration to Erbil from the south and center of Iraq, coupled with climate change that raises temperatures and causes evaporation and decreases precipitation over the region, along with regular water demand during changes in the Middle East, have resulted in increased groundwater fluctuation and irregular well drilling, which has damaged reservoirs and caused a rapid decline in aquifer water availability. the majority of the wells during the periods between 2003 and 2023 need deepening about 100 to 250 m, however, at present the depth of the wells in some areas reaches more than 600 m to 670 m depth.

Erbil Basin Structure

It is important to note that the Erbil basin is unique in that it functions as a syncline, with a core depression and surrounding hilly topography on each side. The basin's dynamics of groundwater recharge and discharge are significantly influenced by these mountains.

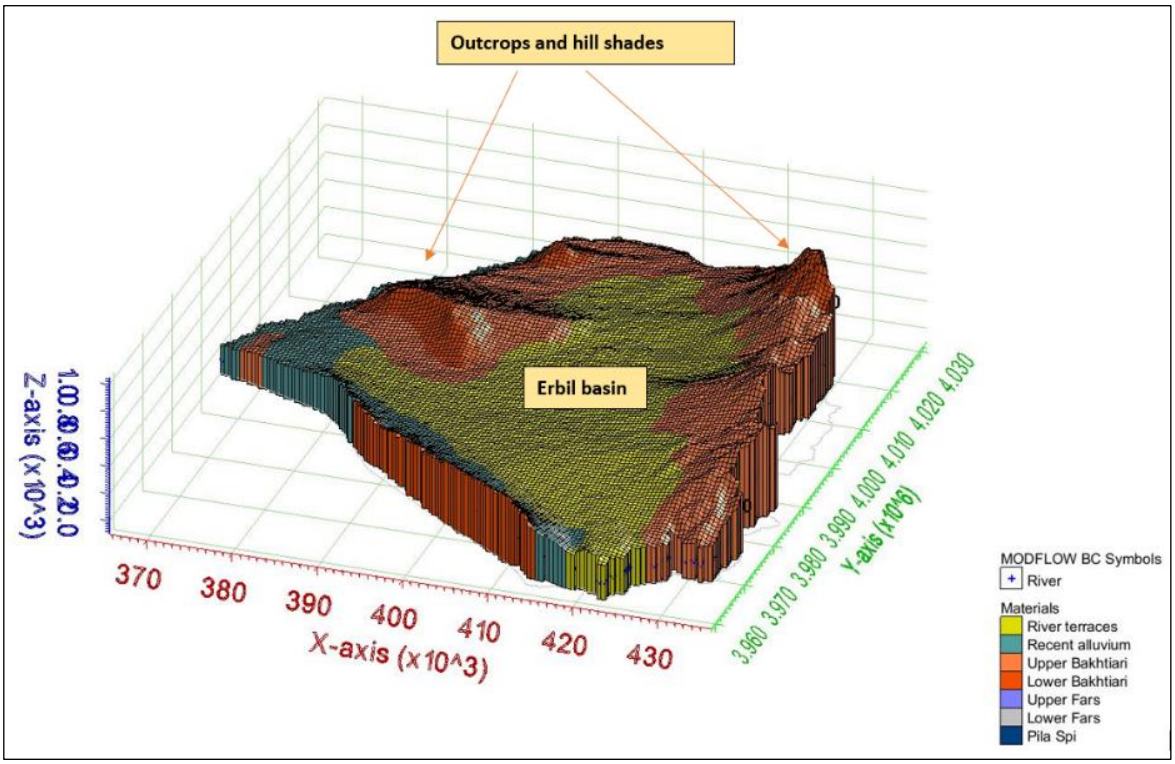


Figure 17: 3D view of Erbil basin formations created by GMS v.10.7

The syncline's central depression serves as a catchment area for water runoff and aids in the creation of subsurface aquifer systems. This geological structure emphasizes the complex

interaction between geological formations and the hydrological processes that define the region, shaping the hydrogeological characteristics of the Erbil basin while also contributing to its scenic and diversified scenery (Shekhmamundy and Surdashy, 2022). See the 3D visualization model created by GMS version 10.7 in Fig. 17.

In addition, to rebuild the Erbil Basin using the most recent hydrogeological maps, drawing new sub-basin borders, and editing any relevant paperwork. Consequently, the initial Configuration for the years 1980–2023 was as follows: Two major sub-basins, JWAN Basin and JWAN S. Basin, were created from the conversion of three sub-basins: Kapran Basin, Middle Basin, and Bashtepa Sub-basin. On the other hand, the Middle Basin is smaller and joined to the Bashtepa Sub-basin. Moreover, the Kapran Basin is divided into the North Sub-basin, known as the [JWAN Basin]. This has been changed in light of the comprehensive computations that have been supplied for the average declination of the groundwater level in each sub-basin. Clearly outline the methodology used to determine the connection of the Middle Basin with the Bashtepa Sub-basin and the separation of the Kapran Basin. such as shown in Fig. 18.

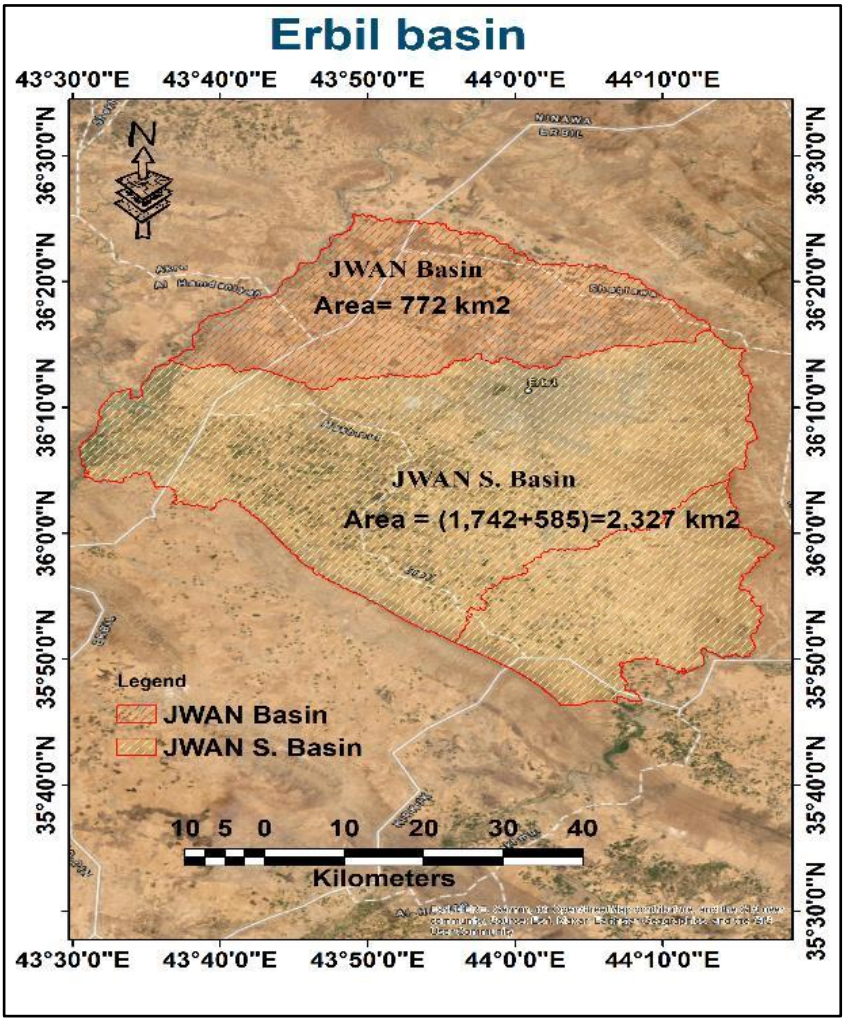


Figure 18: Reconstructed the Erbil basin with new names

Groundwater Flow Direction

Based on data from groundwater level monitoring (Directorate of Erbil groundwater) for every well, a groundwater level contour map was made. The distribution of groundwater potential is shown by the groundwater contour map (Alwaeli and Mohammed, 2021; Hussein and Abed, 2020). From the higher head to the lower head, groundwater flows. As a result, the contour map produced by the groundwater modeling program GMS version 10.7 depicts the direction of groundwater flow. As demonstrated in Fig. 19.

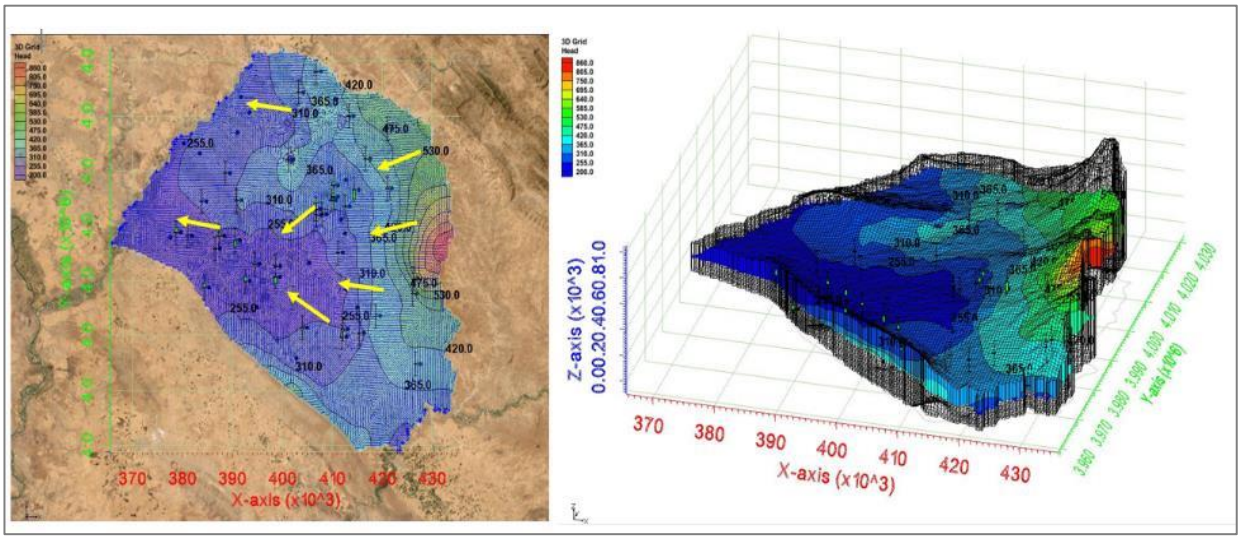


Figure 19: Groundwater flow direction in Erbil Aquifers using (GMS v.10.7)

Fig. 19 shows how the groundwater moves along the head distribution in the direction indicated by the arrows. Furthermore, the groundwater that feeds the Erbil basin originates from rainfall that falls on the hillsides and outcrops. This precipitation seeps into the ground as it travels to the plains, where it becomes groundwater in the Erbil Aquifers. The remaining groundwater then flows to the southwest's agricultural region. On the other hand, groundwater flows toward the Great Zab River in the northern portion of the Erbil basin.

RESULTS AND DISCUSSION

The results of this study involve the following findings:

The Erbil basin's measured temperature range of 19 to 26°C implies a moderate to warm climate, based on the impact of temperature on groundwater. Temperature has a complex effect on groundwater. High temperatures have the ability to modify the viscosity and density of groundwater, which could change the aquifer's flow characteristics. Higher temperatures may also quicken chemical reactions in the aquifer, which could have an impact on the groundwater's general geochemical composition and the dissolution of minerals.

Next, depending on Changes in Electrical Conductivity (EC): The research shows that the Erbil basin has a significant range in EC, ranging from 477 to 1345 µm/cm. The historical background must be understood, since in 1998 the EC values ranged from 215 to 1003 µm/cm, which was a far lower range. This notable rise over time raises the possibility of a relationship with other human impacts, such as climate change.

Comparing the trends in temperature and EC across time: The dynamic character of the Erbil groundwater system is highlighted by comparing the present temperature and EC values with data from 1998. The increase in temperature and EC values could be a sign of long-term patterns linked to human activity or climate change, which could have an effect on groundwater quality and the hydrological cycle. This temporal analysis is essential for understanding the pathway of environmental changes in the region.

The observed increase in EC values may have an influence on groundwater quality based on the effects on the groundwater quality in the Erbil basin. Elevated EC is frequently linked to higher dissolved salt and ion concentrations. The necessity of continual monitoring to evaluate the long-term effects on groundwater quality is shown by the comparison with historical data. Groundwater applications such as drinking water delivery and agricultural irrigation may face difficulties due to elevated EC.

Comparing the study's findings with those of earlier research It is essential to compare the current findings with earlier research conducted in the same area in order to put them in context. Temperature and EC variations could be caused by modifications to land use, human activity, or climatic patterns. A more thorough evaluation of the variables affecting groundwater dynamics in the Erbil basin is made possible by comprehending these variances in light of previous studies, as demonstrated in Table 3.

Ultimately, the observed variations in both temperature and EC highlight the significance of ongoing observation and investigation to follow patterns and evaluate their consequences. Future research ought to examine the precise processes causing these modifications and any possible effects they may have on groundwater supplies. The results also directly affect the management of water resources, highlighting the necessity of adaptive measures to deal with the changing circumstances in the Erbil basin. As a result, the conversation emphasizes how the physical and chemical characteristics of the Erbil groundwater system are linked to temperature and EC. In order to better understand the underlying factors and inform efficient water resource management strategies in the face of climate change and anthropogenic influences, it is necessary to conduct continuing research and monitoring activities due to the observed changes over time.

The data shown in Table 4 show the average groundwater level reduction in three important areas: Kapran, Central, and Bashtepa, in addition to the influence on declining groundwater levels. According to the data, Bashtepa has the largest decrease at 55 meters, Central has a decline of 51 meters, and Kapran experiences an average decline of 33 meters. These figures are calculated using the water level analysis of 55 wells that were used as monitoring locations and provided repeated data throughout the course of the 18 years that were taken into consideration. The estimated 2.57-meter annual average fall highlights a worrying pattern in the groundwater levels in the Erbil aquifers.

As seen in Figure 19, the revised classification identifies the Jwan Basin and Jwan S. Basin as the two primary basins. In response to the noted decline in groundwater levels and variances in water quality throughout the research region, basin borders have been revised. With this

classification, our understanding of the hydrological system in the Erbil groundwater basin is more accurate, marking a substantial refinement. The study emphasizes the need for a dynamic approach to basin delineation by highlighting the temporal changes in the Erbil groundwater basin. Through the integration of data spanning from 1980 to 2023, we are able to accurately depict the current state of the basin while also capturing its dynamic nature. The shift from two primary basins, Jwan Basin and Jwan S. Basin, to three sub-basins represents

CONCLUSIONS

The study concludes that there has been a significant rise in Electrical Conductivity (EC) in the Erbil basin from 1998 to the present, with a range of 477 to 1345 µm/cm, as opposed to the previous range of 215 to 1003 µm/cm. This increase raises the possibility of a connection to other human factors, such as climate change. The Erbil groundwater system is dynamic, as seen by the simultaneous increase in temperature and EC values. This suggests long-term trends related to climate change or human activity that could affect the hydrological cycle. In order to better understand the underlying causes and develop adaptive water resource management techniques in the face of environmental changes, these findings highlight the necessity of continuing observation and research.

Additionally, it was found that this study had critically examined how climate change is affecting the groundwater in the Erbil basin. We have learned a great deal about the changing dynamics of the basin by thoroughly analyzing groundwater levels and water quality from the baseline year of 1980 to 2023. We have adjusted the basin limits in this study to better reflect the actual state of affairs, in line with our main objective of assessing how climate change is affecting this vital water source. The study's findings demonstrate the Erbil Basin's groundwater's susceptibility to climate change, with discernible effects on water quality and groundwater levels.

References

Aladejana, J.A., Kalin, R.M., Sentenac, P. and Hassan, I., 2020. Assessing the impact of climate change on groundwater quality of the shallow coastal aquifer of eastern Dahomey basin, southwestern Nigeria. *Water*, 12(1), p.224. Doi:10.3390/w12010224.

Al-Kubaisi, Q.Y., Hussain, T.A., Ismail, M.M. and Abd-Ulkareem, F.A., 2019. Estimation of water balance for the central basin of Erbil Plain (north of Iraq). *Engineering and Technology Journal*, 37(1 Part C). Doi:10.30684/etj.37.1C.5.

Al-Sudani, H.I.Z., 2019. Estimation of water balance in Iraq using meteorological data. *Int J Recent Eng Sci,* 6(5), pp.8-13. http://ijresonline.com/archives/ijres-v6i5p102.

Alwaeli, J.M., Ali, S.K. and Mohammed, A.H., 2021. Using Geographic Information Systems (GIS) program and Water Quality Index (WQI) to assess and manage groundwater quality in the City of Baghdad. *Journal of Engineering*, 27(3), pp.93-112. Doi: 10.31026/j.eng.2021.03.07.

Azizi, H., Ebrahimi, H., Mohammad Vali Samani, H. and Khaki, V., 2021. Evaluating the effects of climate change on groundwater level in the Varamin plain. *Water Supply*, 21(3), pp.1372-1384. Doi:10.2166/ws.2021.007.

Costa, D., Zhang, H., and Levison, J., 2021. Impacts of climate change on groundwater in the Great Lakes Basin: A review. *Journal of Great Lakes Research*, 47(6), pp.1613-1625. Doi:10.1016/j.jglr.2021.10.011.

Dizayee, R. H. 2014. Groundwater Degradation and Sustainability of the Erbil Basin, Erbil, Kurdistan Region. Iraq. Master, Texas Christian University. Dizayee_tcu_0229M_10532.pdf.

Edition, Fourth., 2017. Guidelines for drinking-water quality: first addendum to the fourth edition. WHO, In (pp.631).

El- Sallag, M., 2001. Assessment of water resources of Erbil governorate- Northern Iraq. UNICEF. (Unpublished).

Faqe, H.M.H.G.R. and Hashemi, S.S.Q.H., 2015. Impact of urban growth on groundwater levels using remote sensing-case study: Erbil City, Kurdistan Region of Iraq. *Journal of Natural Sciences Research*, 5(18), pp. 2224-3186. ISSN (Paper) ISSN 2225-0921 (Online)

Fathy, I., Ahmed, A. and Abd-Elhamid, H.F., 2021. Integrated management of surface water and groundwater to mitigate flood risks and water scarcity in arid and semi-arid regions. *Journal of Flood Risk Management*, 14(3), p.e12720. Doi:10.1111/jfr3.12720.

Hamad, R., 2022. Erbil Basin Groundwater Recharge Potential Zone Determination Using Fuzzy-Analytical Hierarchy Process (AHP) in North Iraq. *Tikrit journal for agricultural sciences*, 22(3), pp.175-190. Doi:10.25130/tjas.22.3.20.

Hamad, T.A., ÇULLU, M.A., BİLGİLİ, A.V. and Akça, E., 2022. Temporal and spatial variation of Groundwater level in Barnaty plain districts using GIS and RS data-Case Study: in Erbil City, Iraq. *Australian Journal of Basic and Applied Sciences,* 16(8), pp. 22-34. Doi:10.22587/ajbas.2022.16.8.3.

Hamed M, Disli E. and Shukur J. 2023. Evaluation of Seasonal a Spatial Variation of Groundwater Quality by Determining Factors Associated with Water Quality Using Multivariate Analytical Methods, Erbil Central Sub-Basin. *Iraqi Bulletin of Geology and Mining.* 19(1), pp. 117-45. Doi:10.59150/ibgm1901a08

Hamed, M.H., 2023. Climate Parameter Uses as Indices For Assessment of Climate Change and Water Balance in Erbil Sub-Basin North–Iraq. *Iraqi Journal of Science*, 64(9), pp.4518-4537. Doi:10.24996/ijs.2023.64.9.19.

Hamed, M.H., 2023. Groundwater quality assessment for different uses using various water quality 'indices in Shamamik basin of Erbil-northern Iraq. *Zanco Journal of Pure and Applied Sciences*, 35(5), pp.72-94. Doi:10.21271/ZJPAS.35.5.7.

Hassan, H.A., 1981. *Hydrogeological conditions of the central art of the Erbil Basin* (Doctoral dissertation, Ph. D. Thesis, Baghdad University, Iraq, p: 180) (unpublished).

Hassan I. O. 1998. *Urban Hydrology of Erbil City Region* (Doctoral dissertation, Ph. D. Thesis, Baghdad University, Iraq) (unpublished).

Hawez, D.M., Mizzouri, N.S., Aziz, S.Q. Mustafa, J.S., and Manguri, SB., 2020. Groundwater Characteristics Assessment in Kurdistan Region Provinces-Iraq: A review. *Journal of Duhok University*, 23(2), pp. 546-83. Doi:10.26682/csjuod.2020.23.2.45.

Horáček, S., Kašpárek, L. and Novický, O., 2008. Estimation of climate change impact on water resources by using Bilan water balance model. In *IOP conference series: earth and environmental science* (Vol.4, No.1, p.012023). IOP Publishing. November. Doi:10.1088/1755-1307/4/1/012023.

Hussein, M.R. and Abed, B.S., 2020. Groundwater simulation and wells distribution at Qazaniyah city in Diyala governorate. *Journal of Engineering,* 26(9), pp.95-113. Doi: 10.31026/j.eng.2020.09.07.

Jwan, S. M., Salah, F. S. A., and Shuokr, Q. A. 2021. Assessment of sustainability and management for groundwater source in Erbil city. *Recycling and Sustainable Development,* 14(1), pp. 41-50. Doi:10.5937/ror2101041M.

Khayyat, H.A.K.A., Sharif, A.J.M. and Crespi, M., 2020. Assessing the impacts of climate change on natural resources in Erbil area, the Iraqi Kurdistan using geo-information and Landsat data. *Environmental remote sensing and GIS in Iraq*, pp.463-498. Doi:10.1007/978-3-030-21344-2_19.

Kumar, C.P., 2012. Climate change and its impact on groundwater resources. *International Journal of Engineering and Science,* 1(5), pp.43-60. CC_GW_Inventy-libre.pdf (d1wqtxts1xzle7.cloudfront.net.

Mawlood, D.K., 2019. Sustainability of Aquifer and Ground Water Condition in Erbil Basin/Iraq. *ZANCO journal of pure and applied sciences*, 31(6). pp.51-60. Doi:110.21271/ZJPAS.31.6.6.

Meng, Q., Liu, Z. and Borders, B. E. 2013. Assessment of regression kriging for spatial interpolation–comparisons of seven GIS interpolation methods. *Cartography and geographic information science,* 40(1), pp.28-39. Doi:10.1080/15230406.2013.762138.

Mustafa, J. S. and Mawlood, D. K., 2023. Estimating of Groundwater Recharge in North, Central, and South Basin of Erbil. *Mathematical Modelling in Civil Engineering,* 18(1), pp. 14-24-2023 Doi:10.2478/mmce-2023-0002.

Mustafa, J.S. and Mawlood, D.K., 2023. Mapping groundwater levels in Erbil Basin. *Am. Sci. Res. J. Eng. Technol. Sci*, 93, pp.21-38. https://asrjetsjournal.org/index.php/American_Scientific_Journal/index.

Nanekely M, Scholz M, and Aziz SQ. 2017. Towards sustainable management of groundwater: A case study of semi-arid area, Iraqi Kurdistan region. *European Water,* 57, pp. 451-7.

Nanekely, M., Al-Faraj, F., and Scholz, M., 2019. Estimating groundwater balance in the presence of climate change impact: a case study of semi-arid Area. *Journal of Bioscience and Applied Research,* 5(4), pp.437-55. Doi:10.21608/JBAAR.2019.114536.

Othman, B.A., and Ibrahim, E.S., 2021. Assessment of groundwater quality over the Erbil Plain based on water quality index. *Zanco Journal of Pure and Applied Sciences,* 33(S1), pp.1-10. Doi:110.21271/zjpas.

Schulz, S., Darehshouri, S., Hassanzadeh, E., Tajrishy, M., and Schüth, C., 2020. Climate change or irrigated agriculture–what drives the water level decline of Lake Urmia. *Scientific Reports,* 10(1), pp. 236. 6 Doi:10.1038/s41598-019-57150-y.

Seeyan, S., Akrawi, H., Alobaidi, M., Mahdi, K., Riksen, M. and Ritsema, C., 2022. Groundwater Quality Evaluation and the Validity for Agriculture Exploitation in the Erbil Plain in the Kurdistan Region of Iraq. *Water*, 14(18), p.2783. Doi:10.3390/w14182783.

Shekhmamundy, I.H. and Surdashy, A.M., 2022. Geomorphological Analysis and Distribution of Landform of Erbil Masterplan Layout. *The Iraqi Geological Journal*, 55 (2F), pp.197-211. Doi:10.46717/igj.55.2F.14ms-2022-12-29.

Soundala, P., and Saraphirom, P., 2022. Impact of climate change on groundwater recharge and salinity distribution in the Vientiane basin, Lao PDR. *Journal of Water and Climate Change, 13*(11), pp.3812-29. Doi:10.2166/wcc.2022.161

Taylor, R.G., Scanlon, B., Döll, P., Rodell, M., Van Beek, R., Wada, Y., Longuevergne, L., Leblanc, M., Famiglietti, J.S., Edmunds, M. and Konikow, L., 2013. Ground water and climate change. *Nature climate change*, 3(4), pp.322-329. Doi:10.1038/nclimate1744.

Toma, J.J., Assad, Z.S. and Baez, D.R., 2013. Water quality assessment of some well water in Erbil city by quality index, Kurdistan REGION-Iraq. *Journal of Advanced Laboratory Research in Biology*, 4(4), pp.125-130. https://e-journal.sospublication.co.in.