American Academic Scientific Research Journal for Engineering, Technology, and Sciences

ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

https://asrjetsjournal.org/index.php/American_Scientific_Journal/index

Mapping Groundwater Levels in Erbil Basin

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Abstract

Erbil Basin is selected as study area, which is located in Kurdistan Region of Iraq, several production wells have been selected for monthly monitoring of groundwater levels. The continuous depletion of groundwater levels has been recorded due to uncontrolled exploitation from both legal and illegal wells, that poses a major problem in the selected basin. The area is classified as arid and semi-arid regions. Accurate prediction of groundwater table maps is required to development the groundwater management strategies for the aquifer system of the study area. Depth to groundwater has been measured for (55) wells that distributed within the Northern, Central, and Southern sub-basins of Erbil. As well as, groundwater levels are mapped and compared the studied data that observed in field with previous recorded data of the same that has been taken by the Directorate of Erbil Groundwater. The methodology of this study is involved mapping groundwater tables for the two different years for the wells, which is observed data in (2022) with surveying wells coordinates as field observations, and compare with data of groundwater tables in (2004) that archived by groundwater directorate. This study employs high-accuracy surveying techniques for the selected wells and utilizes geographic information systems (GIS) as a successful tool for mapping groundwater levels using both Kriging and IDW interpolation methods. The results are indicated successfully that groundwater tables have sudden drawdown during these (18) years by about (-46.86) m. This large drawdown refers to drilling the cluster of uncontrolled wells within Erbil basin without planning. Finally, the study concludes that Erbil basin required better planning and management of Aquifer system, and required to install a set of observation (or piezometer) to monitoring groundwater levels without using production wells because it gives an accurate data, and the fluctuation of the groundwater need to be connected with high accuracy sensor inside observation wells. The study is limited due to the absence of observation wells within Erbil basin. The main aim of this study is to present the existing problems in the study area, it also focusses on the required solutions for development of the groundwater resources and keep the sustainability of this vital resources.

Keywords: Erbil basin; Groundwater levels; Kriging; Inverse Distance Weighting IDW; GIS.

Received: 3/4/2023
Published: 4/20/2023

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1. Introduction

It is important to note that previous studies on the Erbil Basin relied on existing well coordinates from the Directorate; however, many monitoring wells (means the existing production wells used as observing wells) which are alternative new drilled wells were replaced, for various reasons, and new locations' coordinates were not reported properly. Therefore, well locations should be updated using accurate topographic survey methods and instruments. The author notes that most of the wells used for monitoring purposes are active production wells. Hence the quality of the data relies heavily on having the pumping stopped for enough time to allow groundwater to reach its normal static level. Groundwater levels from operational wells may provide dynamic levels that do not represent the natural groundwater level conditions. Therefore, due to the importance of the groundwater in the study area, Erbil basin is selected because there are many problems that should be solved and need to proper managing, which is the major problem in this region.

Since, Groundwater is a vital resource in northern part of Iraq [1] This research study examines the use of GIS to create maps of the groundwater table in Erbil basin, an essential step in groundwater management and planning. Because, the accurate representation of groundwater levels in an aquifer system is crucial for both groundwater modeling and planning for effective management of groundwater resources [2]. More than a third of all water used by humans worldwide comes from groundwater sources, with this percentage being even higher in rural areas where most drinking water depends on groundwater [3]. In this study, Erbil Basin is selected as the study area to address problems related to groundwater depletion in the region. Field data and site visits during the study period when depth-to-groundwater records were taken, also the study confirmed that there are numerous uncontrolled wells within Erbil Basin without proper management or planning for future drought problems. Another main objective of this study is to use accurate well coordinates for mapping the groundwater table. According to [4], successful modeling of groundwater flow requires input from many boundary conditions such as accurate groundwater levels measured at random points covering the aquifers of the study area. As well as, based on the review of literature of previous studies numerous studies have investigated groundwater table and flow direction using remote sensing and GIS applications. For instance, [5] optimized a groundwater level observation network and improved it through the application of Kriging methodology. Reference [4] used Kriging to create contour maps of groundwater levels in India. Reference [6] predicted groundwater depth and elevation for water management in arid areas of southwest Iran's Zagross Mountains and determined the most applicable interpolation method for groundwater depth and elevation using different Kriging methods. Reference [7] employed geostatistics and GIS to model short-term spatial and temporal variability of groundwater levels in India. Reference [3] used GIS to study geographical position, elevation, static water levels, thicknesses, depths, maximum yields, and water sampling in Iraq. Reference [8] applied remote sensing and GIS to map groundwater potential zones using the Analytic Hierarchy Process (AHP) for the Khazir River Basin in northern Iraq.

Reference [1] which is on the Groundwater management in northern part of Iraq. Then the study of [9]. On Towards sustainable management of Erbil groundwater basin which is arid and semi-arid area, also another study of [10] which is on Estimating Groundwater Balance in Erbil basin and determine the effect of the climate change on the area. after that [11] did the study on the Sustainability of Aquifer system and determine the

Ground Water Condition in Erbil Basin, then the study of [12] Groundwater Flow Modeling for Qushtepa Plain in Southern part of Erbil Basin. Lately [13] studied on the Assessment of groundwater sustainability and management in Erbil city. As well as, the study of [14] who Identifying potential sites for artificial Erbil basin groundwater recharge by using GIS and AHP techniques. Similarly, the study of [15, 17] they are worked on the same kriging and IDW interpolation methods. As well as, the study of [18] who studied on the Degradation and Sustainability of the Erbil groundwater basin and also presented the lack of managing the Erbil aquifer system. In addition, the study confirmed that the development of groundwater in Erbil Basin are poorly understood. However, the study shows the importance of water sustainability by estimating the amount of over-exploitation of water and also describing the hydrological conditions of the Erbil basin. Moreover, in order to understand the condition of the aquifer system, the study collected data about the Erbil basin’s hydrogeology, soil classifications, wells number and lithology, and climate and meteorological data as well. Meanwhile, the researcher used the aquifer’s cross sections and groundwater mapping of the basin to estimate the nature of hydrologic units, groundwater fluctuation levels and the flow direction, also described the Erbil basin’s lithology, water level degradation and thickness of the aquifer system. At the end of the study, it determines that sustainability of Erbil basin and lack of the groundwater management.

This study is necessary for mapping the groundwater levels in Erbil three sub-basin to achieve sustainable management of this resource. This research updates surveying data for selected wells in the Erbil Basin used for observation purposes and monthly measurement of depth-to-groundwater by the Directorate of Erbil Groundwater. It also useful for those researchers who work on determining direction of the groundwater in the study area and as well as for the area having similar conditions.

1.1. Description of the study area

Erbil basin is one of the major groundwater basins in the middle east, it is located in northern part of Iraq, in Kurdistan region governorate. The study area depends on two main sources of water which are both surface and groundwater. This basin occupies the plain area of Erbil governorate. The region is classified as arid or semi-arid Erbil basin covers the area of approximately 3,200 km^2[11]. The basin area was estimated using GIS techniques to update the boundary. The study area is bounded by two rivers: The Greater Zab river at north-west and the Lesser Zab river at south-east of the study area. It lies between coordinates 36°00’00" and 36°20’00" north and 43°20’00" and 44°20’00" east, see (Figure 1):

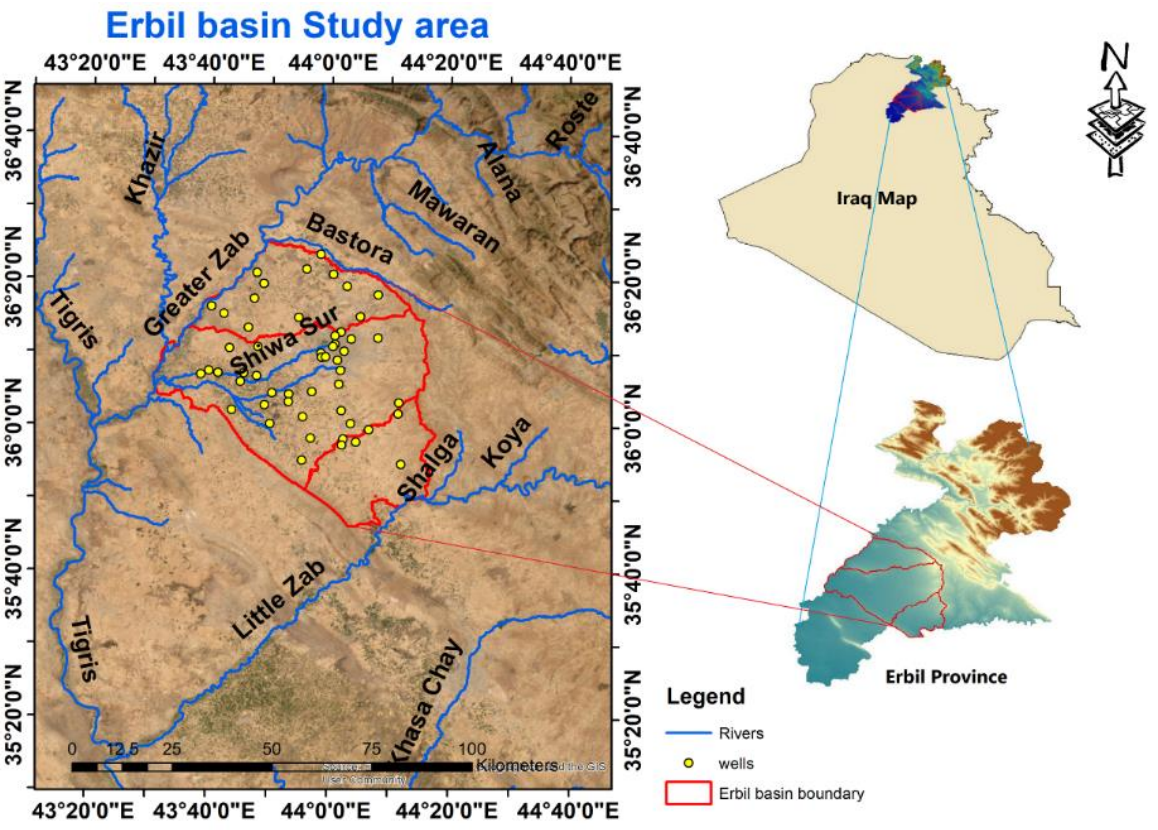

Figure 1: Location of the study area.

1.2. Erbil Basin

Erbil basin is divided into three main sub-basins which are depended on the hydrogeology and geological conditions of the study area according to [11], the known names of each sub-basins are as:

- Northern sub-basin (Kapran)
- Central sub-basin
- Southern sub-basin (Bashtepa), see Figure 2:

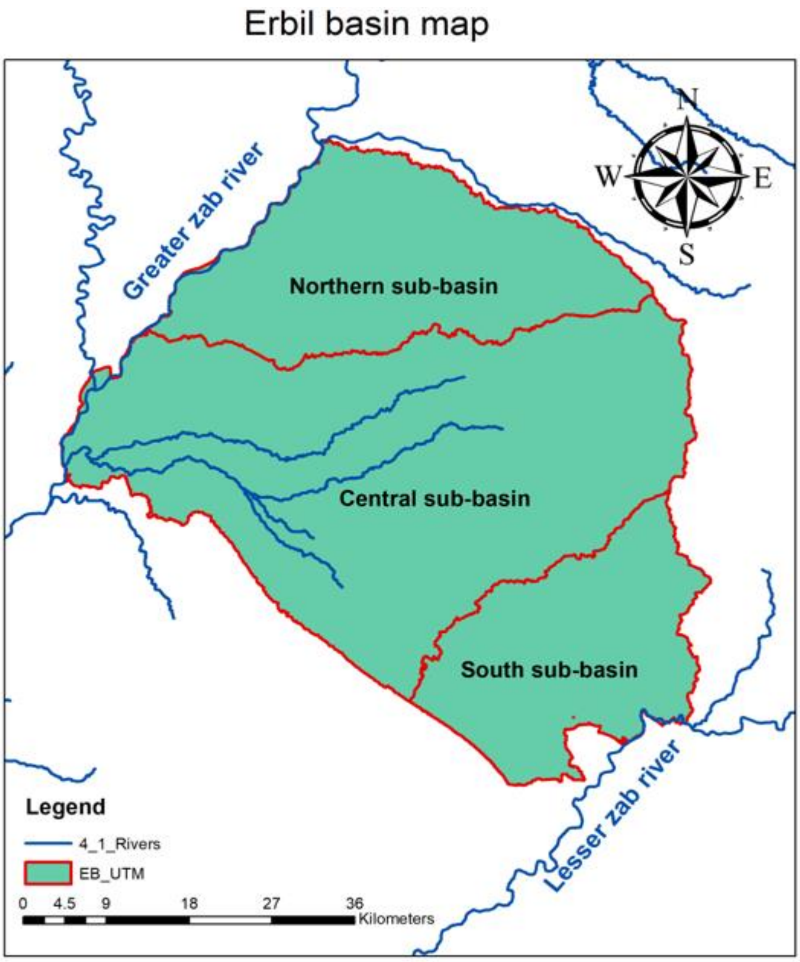

Figure 2: Map of the Erbil three sub-basins [Arc Map, 10.8].

2. Surveying Works and Data Collection

Data collection for this study involved site visits to all monitoring wells selected by the Directorate of Erbil Groundwater for monthly water level measurements. The coordinates and elevations of these wells were surveyed, depth-to-groundwater measurements were recorded, and additional well details were collected from archived documents at the Directorate of Groundwater in Erbil.

All monitoring wells were surveyed with high accuracy (error less than 2.5 mm) using e-Survey (E600) GNSS equipment. The survey used RTK (Real Time Kinematic) technology, which uses communication with Global Network of Survey Satellites (GNSS) with corrections provided dynamically from a local coordinate correction broadcasting on internet. These corrections are needed to negate the effect of atmospheric conditions on satellite coordinate accuracy.

The corrections use a local base point with known exact coordinates. Coordinates were recorded in Latitude/Longitude as well as in UTM (EPSG:32638 - WGS 84 / UTM zone 38N), which is widely used for coordinates in Iraq. Updated well data are summarized in Table 1.

Table 1: The surveying wells coordinates by UTM.

ID	Well Names	X	Y	Z
1	Kasnazan	421958.1	4006820	589.674
2	Gullan	415315.5	4006575	451.362
3	Shorsh	412696.1	4008358	433.589
4	Salahaddin	411180.3	4007371	412.368
5	Bahirka	414273.5	4019968	489.373
6	Nawroz	407624.6	4003038	387.374
7	Shadi	407810.4	4001974	386.095
8	Bahar	408873.4	4002111	393.003
9	College of science	411773.5	4001200	411.834
10	Badawa	413460.3	4003547	427.276
11	Khazna	391536.3	3997359	305.253
12	Nogharan	384761.4	4004438	332.146
13	Zaga	377587.5	3997862	254.57
14	Abasseia	379669.5	3998777	261.659
15	Pemabira	381927	3998210	269.885
16	Saadawa	387500	3995849	286.327
17	Tarjan	388381.4	3998129	293.417
18	Satoor	391871.4	4004655	431.26
19	Sebiran	402125.7	4012026	376.268
20	Jadida zab	391058	4016988	318.258
21	Kawraban	389542.3	4009585	417.361
22	Khabat	380287.8	4015038	286.684
23	Chalugi gchka	383464.6	4013202	346.476
24	Kawrgosk/1	391725.1	4023473	292.37
25	Gainj	393451.4	4020660	310.673
26	Grda chal	404224.9	4024296	387.03
27	Qafar	407708.3	4028060	436.104
28	Jazhnikan ababakr	410844.2	4023007	457.729
29	Mala omer	422026.2	4017715	629.191
30	Shawis	417588.4	4012224	511.48
31	Murtka shahab	412774.3	3988468	400.704
32	Qushtapa badil/12	413134.6	3981223	398.105
33	Qultapa yaba	412816.2	3979754	382.097
34	Hamza kor	416389.5	3980455	413.937
35	Grd mala	415049.6	3985171	413.524
36	Kardiz	419607.8	3983576	446.059
37	Azyiana	427599.4	3974850	439.417
38	Bestanay gawra	426966.9	3987634	586.652
39	Lajan	427156.9	3990396	643.69
40	Daratoo	412115	3995105	414.626
41	Grdarasha	412563.4	3998605	411.433
42	Baghi shar	411174.3	4005306	408.463
43	Glkand	410708.8	4004656	404.001
44	Qoritan	405404.5	3993253	358.536
45	Daldaghan	399572.6	3992669	335.079
46	Sorbash hwez	399553.4	3990696	327.116
47	Tandora	395414.4	3993027	313.046
48	Mastawa	393520.8	3989945	302.984
49	Shekh sherwan	385320.8	3988750	298.203
50	Grd azaban	394914	3985200	308.859
51	Qurshaghu new	402861.8	3975892	337.397
52	Qurshaghu old	402865.1	3975894	337.137
53	Dugrdkan	405005.8	3981463	344.274
54	Pirdawd new	403053.5	3986923	341.432
55	Pirdawd old	403054.3	3986931	341.208

Data analysis was performed using Geographical Information Systems (GIS) with Kriging and IDW interpolation methods for mapping groundwater levels in Erbil's three sub-basins: North, Central, and South (also referred to as KAPRAN, CENTRAL, and BASHTEPA in some studies). Site visits and surveying work are shown in Figure3:

Figure 3: The sample of the field works and surveying of the wells.

3. Methodology and Data Interpretations

In this study, various applications and software were used for data analysis. Microsoft Excel was used to plot charts of groundwater levels in the study area, while GIS (Geographic Information Systems) was used to create Erbil Basin groundwater level interpretation methods using Kriging and inverse distance weighting (IDW) techniques. GIS provides hydrologists with an ideal computing platform for data analysis, parameter estimation, mapping, and visualizing results for multiple purposes, facilitating the design, calibration, and implementation of various subjects [15] Regression kriging is a powerful spatial interpolation method; however stochastic co-kriging, universal kriging or ordinary kriging may be superior in practice compared to simpler deterministic methods such as IDW or radial basis functions. Co-kriging may provide better results in some circumstances [16] Interpolation is a method of using various points with known values to estimate values at other unknown points, which can be used to predict unknown values for any data, for instance: elevation, rainfall, and other geographic data. The method involves kriging and IDW methods for estimate the groundwater levels maps in Erbil basin [17]

3.1 Mapping Groundwater Levels by Kriging

Kriging is a geostatistical method for estimating values in unknown areas by considering both the distance and variation between known data points. It involves creating an estimated surface from scattered points with z-values by fitting a mathematical function to nearby points. The process includes statistical analysis, variogram modeling, surface creation, and variance exploration. Kriging is suitable when data has spatial correlation and is often used in soil science and geology. Predicted values are calculated using a weighted average technique based on the relationship between samples. The search radius can be fixed or variable and generated cell values may exceed the sample range [17]

The Kriging Formula is similar to IDW in that, it weights the surrounding measured values to derive a prediction for an unmeasured location. The general formula for both Kriging and IDW interpolators is formed as a weighted sum of the data as below:

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

where:

Z(Si) = 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

In IDW, the weight, (λi), depends only on the distance to the prediction location. However, in the kriging method, the weights are based not only on the distance between the measured points, and the prediction location but also on the overall spatial arrangement of the measured points.

The Kriging method is an interpolation method based on principles of zero bias and minimum mean square error. It determines values for a process over an entire domain, finite-volume block or specific point using a linear combination of data values. The summation may be over an entire area or restricted region centered at the estimation point [2]

The map of the Erbil groundwater Basin was created using the well measurements (depth to groundwater level) for each of the selected wells. The purpose of these maps is to show the distribution of water table throughout the entire basin, and also identify relatively shallow and deeper parts of the basin. As well as, determining the geometry of the basin. Observed data involving depth-to-groundwater level measurements were subtracted from ground surface elevation to obtain a groundwater table map. This data was entered into GIS and a groundwater level map was created using Kriging interpolation tools, the maps are created for May 2022 (Figure 4).and compared with data of May 2004 (Figure 5):

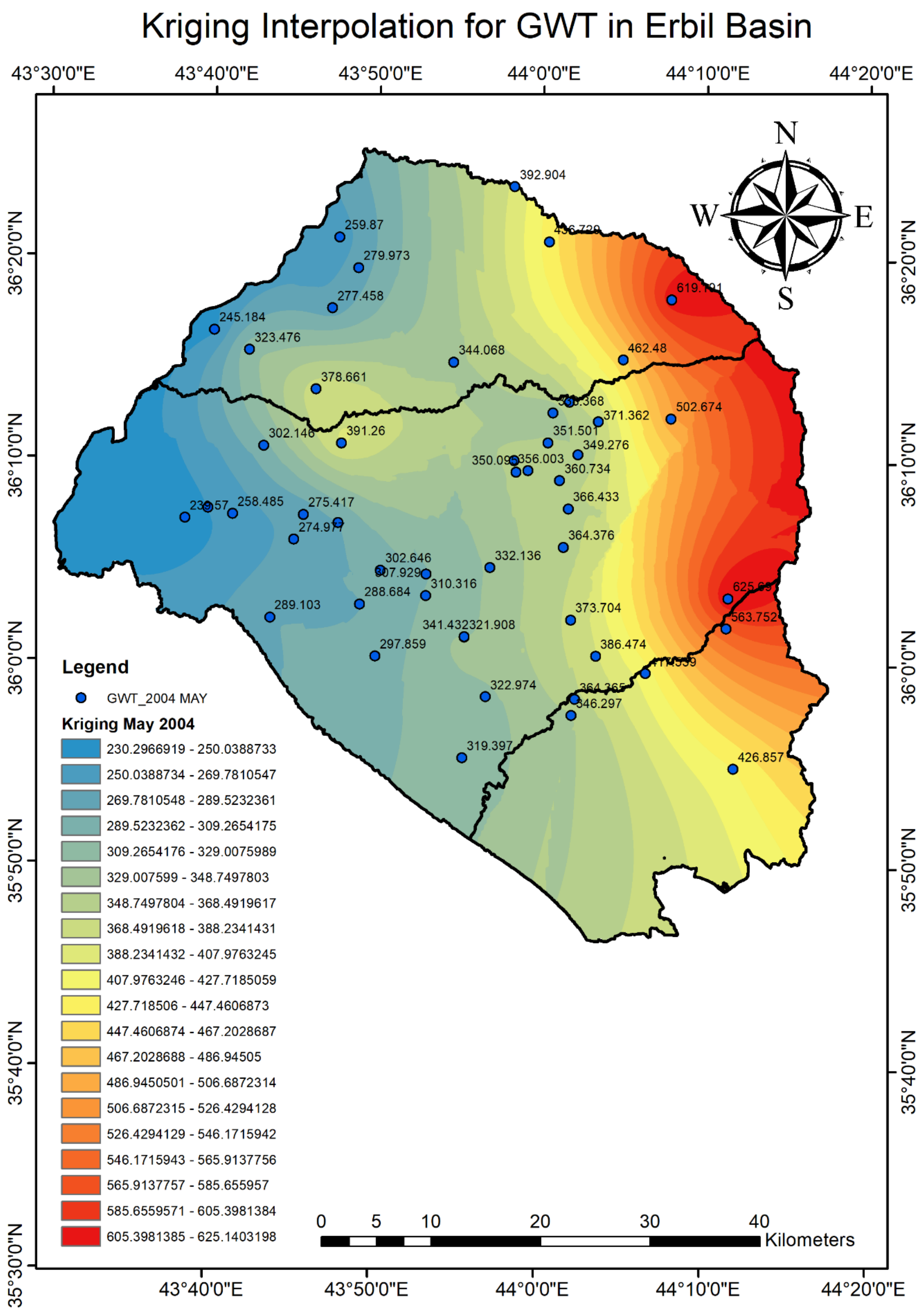

Figure 4: Mapping groundwater levels by Kriging method for may (2022).

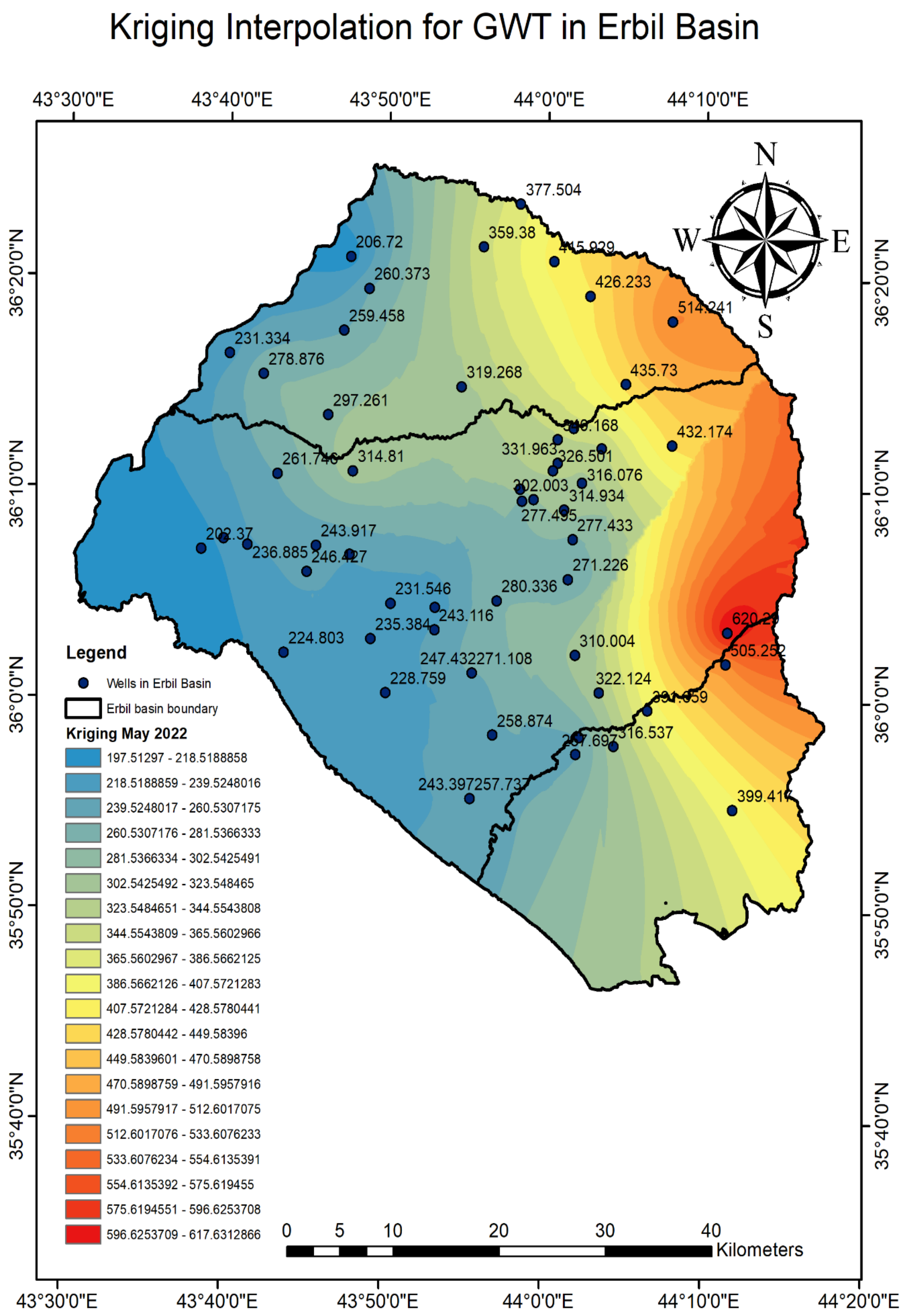

Figure 5: Mapping groundwater levels by Kriging method for may (2004).

3.2 Mapping Groundwater Levels by IDW

In IDW, the weight assigned to each point depends only on its distance from the location being predicted. However, with kriging, weights are determined not just by distance, but also by the spatial distribution of all measured points. To do this, spatial autocorrelation must be calculated. In ordinary kriging, weights are based on a model fitted to the data, the distance to the prediction location, and the spatial relationships among nearby measured values. The kriging formula is used to create both a map of predicted values and a map of prediction accuracy [17] Observed data involving depth-to-groundwater level measurements were subtracted from ground surface elevation to obtain a groundwater table map. This data was entered into GIS and a groundwater level map was created using inverse distance weighting (IDW) interpolation tools. the maps are created for May 2022 (Figure 6).and compared with data of May 2004 (Figure 7):

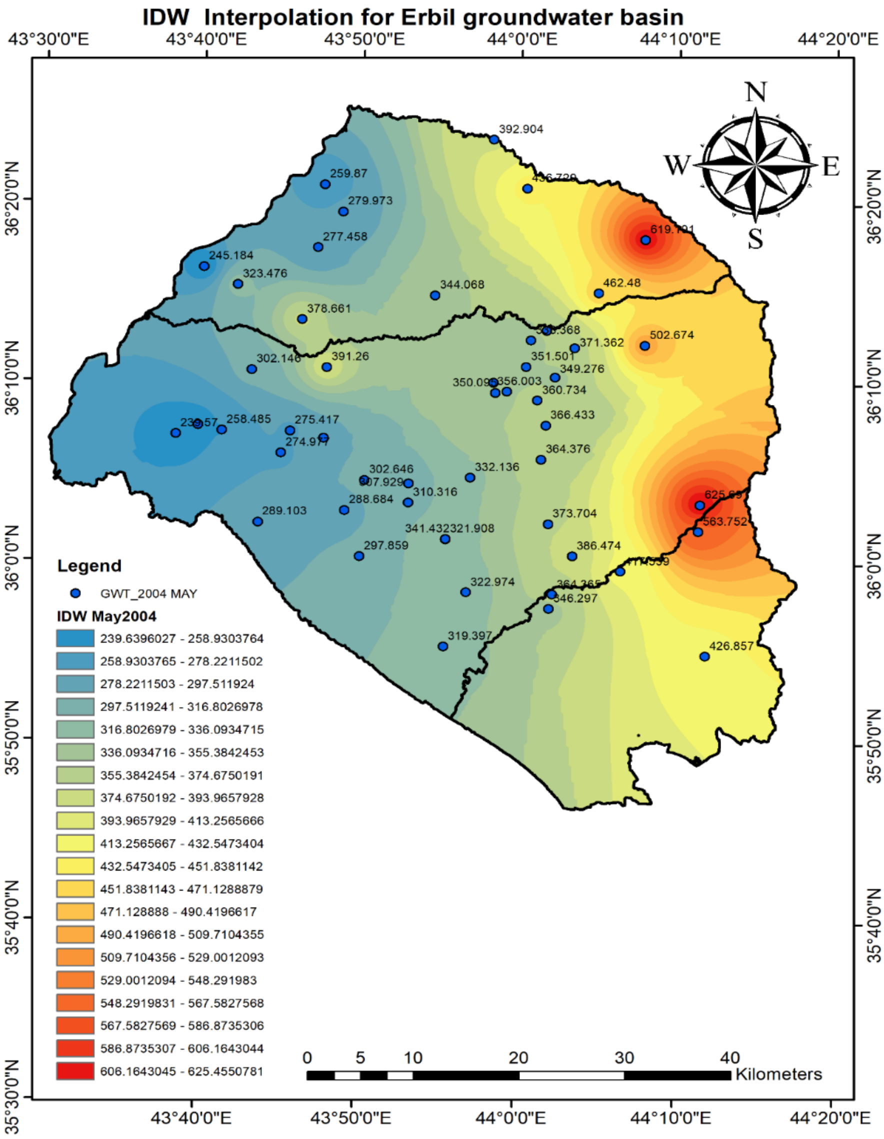

Figure 6: Mapping groundwater levels by IDW method for may (2004).

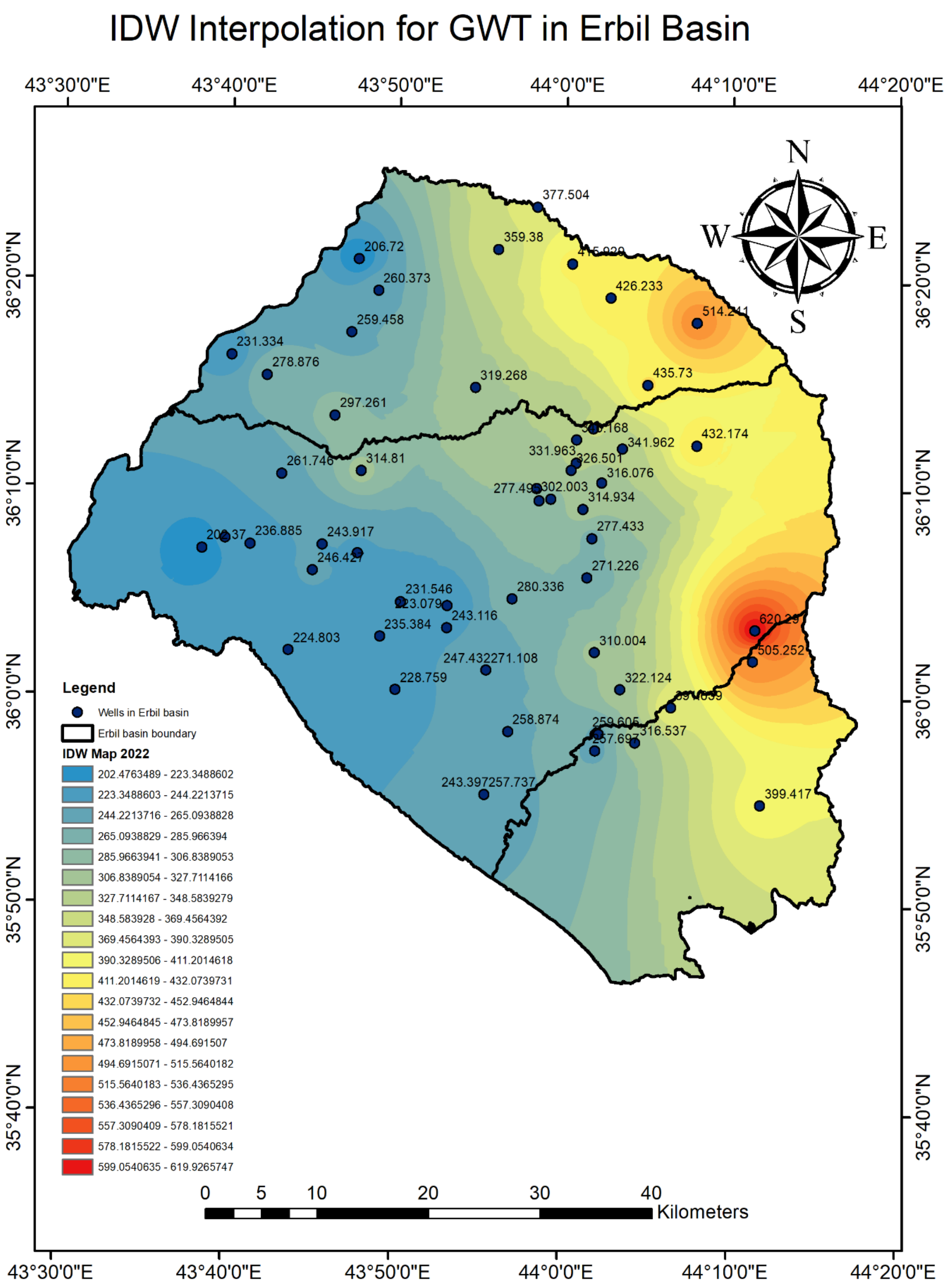

Figure 7: Mapping groundwater levels by IDW method for may (2022).

The two methods of interpolations are different from each other. In General, Kriging method is more precise than IDW but needs certain expertise and knowledge with topographic situation. A basic assumption of Kriging is that is changing the spatial correlation within the area. Also use Kriging when there is a spatially correlated distance or bias in the data. The difference between the two methods are represented clearly in mapping the groundwater levels. In IDW method cell values are determined using a linearly weighted combination of a set of sample points. And the weight is a function of the inverse distance between the values. As well as, the surface should be that of dependent variable based on the locations. And the measured data are relative to the unmeasured locations that have the most influence values in the result. On the other hand, there are three forms of kriging interpolations such as; Simple, Ordinary and Universal, each form with different assumptions, and the forms of the estimator and the resulting equations that determine the coefficients in the estimator. Meanwhile, the IDW interpolation does not have any theoretical foundation. Also, it is not relying on any statistical assumptions. Consequently, it is impossible to decide whether the IDW interpolation method is good or bad. In the case of kriging it must be use the data to choose a variogram or covariance function and in the case of a small number of data locations this is more difficult due to limitations of information and insufficient data.

3.3 Variations in Groundwater Levels in Erbil Basin

A cluster of wells exists within Erbil's three sub-basins. Water depth-to-groundwater level data for these wells was collected between May 2004 to May 2022 during fieldwork in cooperation with Groundwater Directorate staff. The obtained data was plotted on a bar chart to show differences in groundwater levels over time (Figure 8):

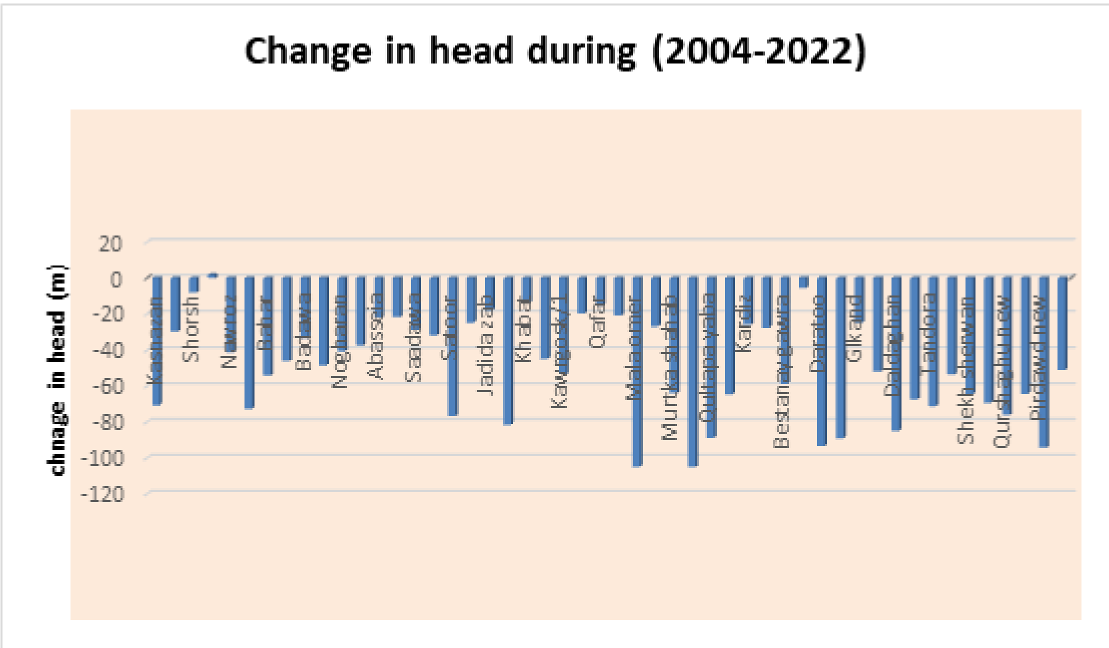

Figure 8: decline groundwater table in Erbil basin between (2004-2022).

The above figure, shows that there are wells with large depletion in groundwater table, and on the other hand, there are wells less declined, the most of the wells that in Northern (Kapran) sub-basin that near to the greater Zab river and at the recharge area have less depletion in head of the groundwater due to having interaction with the area that near to the river, otherwise, the wells at the center of Erbil basin are most declined in head.

The study computed that the average change in groundwater head for Erbil three sub-basins, that are summarized in Table 2:

Table 2: The estimated average groundwater drained for Erbil three sub-basins during May (2004-2022).

Sub-basin	Avg. decline in 2004 (m)	Avg. decline in 2022 (m)	difference between (2004-2022)
Northern (Kapran)	-32.96	-67.44	-34.47
Central	-33.20	-84.73	-51.54
Southern (Bashtepa)	-24.94	-79.52	-54.58
Average	-30.37	-77.23	-46.86

Form the above table, it is clear that the average depletion in groundwater in (2004) are (-32.96, -33.20, and -24.94) m for each sub-basins of Kapran, Central and Bashtepa respectively, whereas the average depletion in groundwater in (2022) are (-67.44, -84.73 and -79.52) m for each sub-basins of Kapran, Central and Bashtepa respectively, this mean that the depth to groundwater in (2004) much higher that that in (2022). On the other hand, the change between the two years (2004-2022) area (-34.4, -51.54 and -54.58) m for each sub-basin of Kapran, Central and Bashtepa respectively. It can be said that the total average decline in depth to the groundwater in 2004 is about (-30.37) m over the entire of Erbil basin. Meanwhile, the total average decline in depth to the groundwater in (2022) is about (-77.23) m, which means that the change in depletion in the groundwater table since 18 years ago are about (-46.86) m. Unfortunately, the data presented in this study only includes legally recorded wells; however, according to [18] an estimated 6.2% of wells in the study area are illegal. ArcGIS (Geographic Information Systems) was used to create a map of wells within the study area; existing wells were plotted on this map for greater detail (Figure 9):

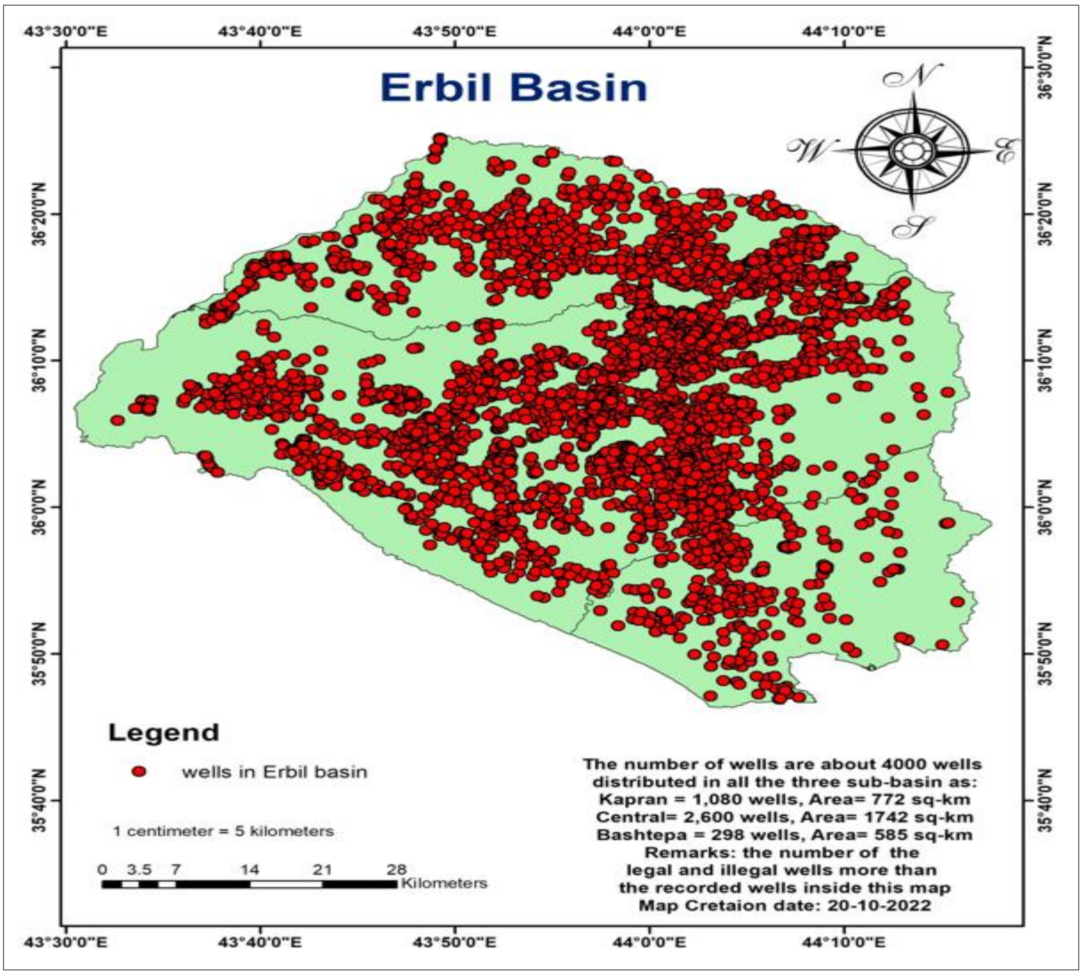

Figure 9: The cluster of wells within Erbil Three sub-basins.

It is obvious that numerous groundwater wells within the selected Erbil basin required to be better managing the groundwater source to keep sustainable for future generation. However, this cannot be achieved inside Erbil basin, due to unknown number of the existing wells. The accurate managing for aquifer system is required. These all can give the accurate water budget in the selected basin. Great depletion of groundwater resources, which is the worst cases and may cause to damage of aquifers, has been recorded at many locations in arid regions in the Middle East [1].

4. Results and Discussions

Based on the results of this study, groundwater levels in Erbil basin declined about (-46.86) meters. The maps are show that the groundwater table in (2004) much higher than in (2022), such as shown in (Figures 3-7). The decline in groundwater table is due to drilling a cluster of illegal and legal wells without any policy and managing aquifer storage and recovery consideration. Thus, if the maps are compared with each other, it seems that the Kriging interpolation method is an efficient method for mapping the groundwater levels for Erbil basin that assists in reducing prediction error. However, the IDW interpolation is one of the simplest and most popular interpolation techniques for various mapping. In addition, In IDW method only known values of (z) and distance weights are used to determine unknown areas such it is presented in the maps. However, the Kriging method is the most appropriate if there is a spatially correlated distance or directional bias in the data. Whereas, IDW method is different from Kriging method in that no statistical models are used. There is no determination of spatial autocorrelation taken into consideration.

As well as, the study shows that there is lack of data of groundwater basin and improper managing the aquifer system lead to decrease in the head. Also, the numerous numbers of the drilled wells in the study area. However, the Erbil basin groundwater is poor management and many studies are confirmed that such as [11, 18] who stated that in Erbil basin, due to cluster of wells and lack of managing the groundwater resources, Additionally, the number of existing wells in each sub-basin exceeds the recorded number due to unknown values of the uncontrolled illegal wells. Moreover, rapid population growth in the Erbil area has increased water demand for multiple purposes. It is important to address water crises during summer drought periods and increase techniques for recharging groundwater sources in the Erbil Basin. Based on both Kriging and IDW interpolation maps, water elevations in the Erbil Basin flow from higher points towards lower elevation positions directed southwest towards Greater Zab River. For mapping the groundwater table in Erbil three sub-basins GIS applications were used to analyze spatial data for wells.

Thus, the study involves mapping of the groundwater levels in two different times, first including measuring depth to groundwater table in time of this study which is on May 2022, and comparing with the same well's depth to groundwater since May 2004, that measured by directorate of Erbil groundwater. A number of wells selected for the purpose of monitoring groundwater fluctuations. Every month directorate of Erbil groundwater records depth to groundwater for the several production wells that are selected for monitoring groundwater table in Erbil province, the number of wells within Erbil basin are about (55) wells, the same wells used by researcher to make comparison the decline in head of the aquifer system, and as well determining the reason behind these large differences. The purpose of this study is to present the large difference between groundwater levels during (18) years ago and explaining the decreases in aquifer water over time. Thus, the results from this study indicate that groundwater levels continue to decline over time. This can be an excellent source for developing the groundwater policy and decision makers to plan best strategies for the groundwater management.

5.Conclusion

This study presents two common interpolation methods for mapping Erbil basin groundwater table. These methods of interpolation applied on Erbil three sub-basin, because the accurate estimation of ground water levels is very important for managing water resources. This study concluded that IDW interpolation is the deterministic method while the Kriging interpolation is a geostatistics method. And the IDW assesses the predicted value by taking an average of all the known locations and determining greater weights to closest points. Both methods rely on the similarity of nearby sample points to create the surface. Using mathematical functions by Deterministic techniques for interpolation purposes. As well as, the Geostatistics relies on both the statistical and the mathematical methods, that can be used to mapping surfaces and assess the uncertainty of the predictions.

In Erbil basin, the Groundwater is considered as a main resource of water supply due to its continual availability. it mainly depends on this resource because it is the only source available after surface water for multipurpose activities through the drilled wells. The rapid growth of the population and the over-exploitation of the groundwater leads to sudden drawdown in aquifer system. It is clear that the water level in (2004) much higher than the groundwater level in (2022), this due to drilling a numerous of legal and illegal wells inside the basin. However, the authority struggle to avoid of the drilling illegal wells, but still to overcome the unknown wells, because the illegal wells have many impacts on damaging the aquifer system and decreases the efficiency of the existing operation wells inside the basin. Accordingly, the unknown wells directly have effect on the developing the strategy of the groundwater basin and avoid keeping sustainability of this vital resources as well. Moreover, Erbil city consumes large amount of water without any policy towards using of water resources and sustainability. In spite of this, lack of people awareness has a significant impact on the depletion of groundwater levels. The results show that there is a decrease in the groundwater level by (-46.86) meters during (18) years ago. Finally, this study confirmed that the continued neglect and irresponsibility in the use of Erbil groundwater resources, will cause to large depletion in water level and drought in the near future.

Acknowledgements

I would like to thank Sherko Sharif, P.Eng., an international expert, for his guidance through personal communications. I would also like to thank Nazir, Director of Groundwater Directorate, and his geologist staff (Abdul Salam, Abdul Qadir, Shakhawan, Soran) for their time spent visiting wells within the Erbil Basin. Many thanks also go to Sarmad, head of the groundwater level department and geologists Hawkar Ajeeb and Sarmad Dilshad for their continuous support and guidance during fieldwork. Special thanks go to surveyor Rizgar Muhammad Amin Rashid for his help during site surveying and patience with work. Finally, I would like to thank all those who provided help during this study.

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