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Developing Spatial Models of Groundwater Quality in the Southwestern Desert of Iraq Using GIS, Inverse Distance Weighting, and Kriging Interpolation Techniques

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ABSTRACT

Water scarcity is a prevalent issue in Iraq, and groundwater resources are critical for addressing this problem, particularly in the country's desert regions. This study aimed to assess groundwater quality and develop spatial models using geographic information systems (GIS), inverse distance weighting (IDW), and Kriging interpolation techniques in the southwestern desert of Iraq. Water samples were collected from 75 wells, spanning an area of 50,488 km², and were analyzed during both the dry and wet seasons. The water quality characterization included measurements of electrical conductivity (EC), total dissolved solids (TDS), pH, and major cations and anions in the groundwater. Results indicated a high range of TDS values, corresponding to elevated EC levels, with pH values ranging from 7.1 to 8.3 across the study area, as revealed by the GIS models. It was found that the concentrations of major cations (Ca and Mg) and anions (HCO_3, Cl, and SO_4) exceeded the acceptable limits for drinking water set by the World Health Organization (WHO) and Iraqi drinking water specifications, with noticeable variations in the distribution of these elements within the study area. Furthermore, seasonal fluctuations were observed to have a significant impact on the groundwater quality characteristics. In conclusion, a wide range of water quality characteristics was identified in the study area, and the developed spatial models can serve as valuable tools for selecting appropriate treatment methods to utilize groundwater as a drinking water source.

1. Introduction

Water is the essence of life, and many regions globally face water scarcity due to climate change and pollution issues [1-3]. Surface water pollution exacerbates these problems by spreading organic and inorganic contaminants [4, 5]. Consequently, groundwater has become an essential water source for various purposes worldwide. Groundwater refers to water present beneath the Earth's surface in soil pores, rocks, and saturated geologic formations [6]. This topic has garnered significant attention from researchers who have investigated groundwater quality in diverse regions. For example, Pamei et al. [7] evaluated groundwater physicochemical properties and sustainability in Nagaland, India, while Adimalla [8] assessed groundwater quality for drinking and irrigation in a semi-arid region of South India. Mallick et al. [9] reviewed numerous studies conducted in Saudi Arabia, highlighting groundwater issues in that region.

Iraq, characterized by a semi-arid climate, is one of the countries affected by water scarcity due to climate change [10-12]. Large portions of its land consist of desert areas, particularly in the western and southwestern regions, where surface water is limited or non-existent. Moreover, Iraq's water resource sector has suffered from the consequences of wars, political struggles, and economic changes over the past four decades. Consequently, exploiting groundwater as a primary water resource for drinking and irrigation purposes has become crucial. Several studies have recently focused on groundwater in Iraq [13-15]. For instance, Alkam et al. [16] investigated the physical and chemical properties, as well as algal content, of two wells in the Al-Rrehba area, south of Bahr Al-Najaf, Iraq, over a six-month period from November 2007 to April 2008. The results indicated that the water from both wells was slightly alkaline, hard, and contained oxygen levels above critical values. Furthermore, statistical analyses did not reveal any differences between the water's physical and chemical properties during the study period. Hussain et al. [17] evaluated and modeled groundwater suitability for irrigation using an Irrigation Water Quality Index (IWQI) and Geographic Information System (GIS) in the Al-Najaf governorate of Iraq. They applied the model to the Damman aquifer in western Iraq, selecting 39 locations for assessment during the dry and wet seasons of 2013. The chosen variables included pH, electrical conductivity (EC), total hardness, Mg, Ca, Na, Cl^-, and the sodium adsorption ratio (SAR). The results based on the proposed model indicated that water quality in the area was marginally suitable for agricultural purposes.

Ghalib [18] studied groundwater quality characteristics in the northeastern areas of Wasit province, located in the central part of Iraq, by analyzing chemical and physical parameters from 98 samples collected from scattered shallow wells. The parameters included major cation and anion compositions, pH, total dissolved solids (TDS), and electrical conductivity (EC), all of which were assessed to determine groundwater quality for drinking purposes. Understanding the most critical hydrochemical parameters of groundwater is essential for capitalizing on valuable water sources and effectively predicting and protecting changes in groundwater quality [19, 20]. Water quality parameters such as pH, EC, TDS, major cation concentrations (Ca, Mg, Na, and K), and major anion concentrations (CO_3, HCO_3, Cl, and SO_4) govern the suitability of water for various purposes, including drinking. Groundwater quality suitability analysis and mapping processes based on Geographic Information Systems (GIS) are crucial for groundwater planning strategies.

El-Rawy et al. [21] employed GIS, factor analysis, and hydrochemistry to evaluate groundwater quality for irrigation and drinking in Egypt's Qena Governorate. They collected and analyzed 73 groundwater samples for pH, EC, TDS, and various chemicals, including HCO_3, Cl, SO_4, F, Mg, Ca, Na, K, and total hardness. Their results were compared to the World Health Organization (WHO) and Egyptian water standards, revealing that approximately 62% of groundwater wells were potable, and 99% were suitable for irrigation. However, the influence of seasonal variations, such as wet and dry seasons, on groundwater quality and its suitability for drinking, irrigation, and industrial use should also be considered [22].

As previously mentioned, Iraq suffers from water scarcity, and exploring groundwater quality in desert areas using GIS models could help address this issue. Inverse distance weighted (IDW) interpolation uses a linearly weighted set of sample points to estimate cell values for a location-dependent variable's surface [23]. Kriging is an advanced geostatistical procedure that generates an approximated surface from z-valued points. To effectively apply the Kriging tool, it is crucial to investigate the spatial behavior of the z-values before selecting the optimal estimation method for constructing the output surface [24]. These methods yield the least errors and the most similar data distribution can be selected [25].

Thus, the main objective of this study is to construct a spatial model using GIS and IDW and Kriging techniques for the groundwater quality parameters in the southwestern part of the Iraqi desert, based on the physical and chemical analysis of groundwater water quality parameters. As well as the spatial distribution of groundwater quality parameters by using GIS evaluates the changes in water quality sensitivity during dry and wet seasons and is compared with Iraqi and WHO standards for drinking water.

2. MATERIALS AND METHODOLOGY

2.1 Location and description of the study area

The selected study area was located in the southwestern part of the Iraqi desert. This area included parts of three Iraqi governorates: Muthanna governorate, Dhi-Qar governorate, and Basra governorate. The selected area is bordered by the State of Kuwait to the south, to the west and southwest by the international borders of Kingdom of Saudi Arabia, as shown in Figure 1. The area of the study region was about 50,488 km^2, and lies between 44° 40' - 48° 00' East longitudes and 29° 00' -31° 20 North latitudes.

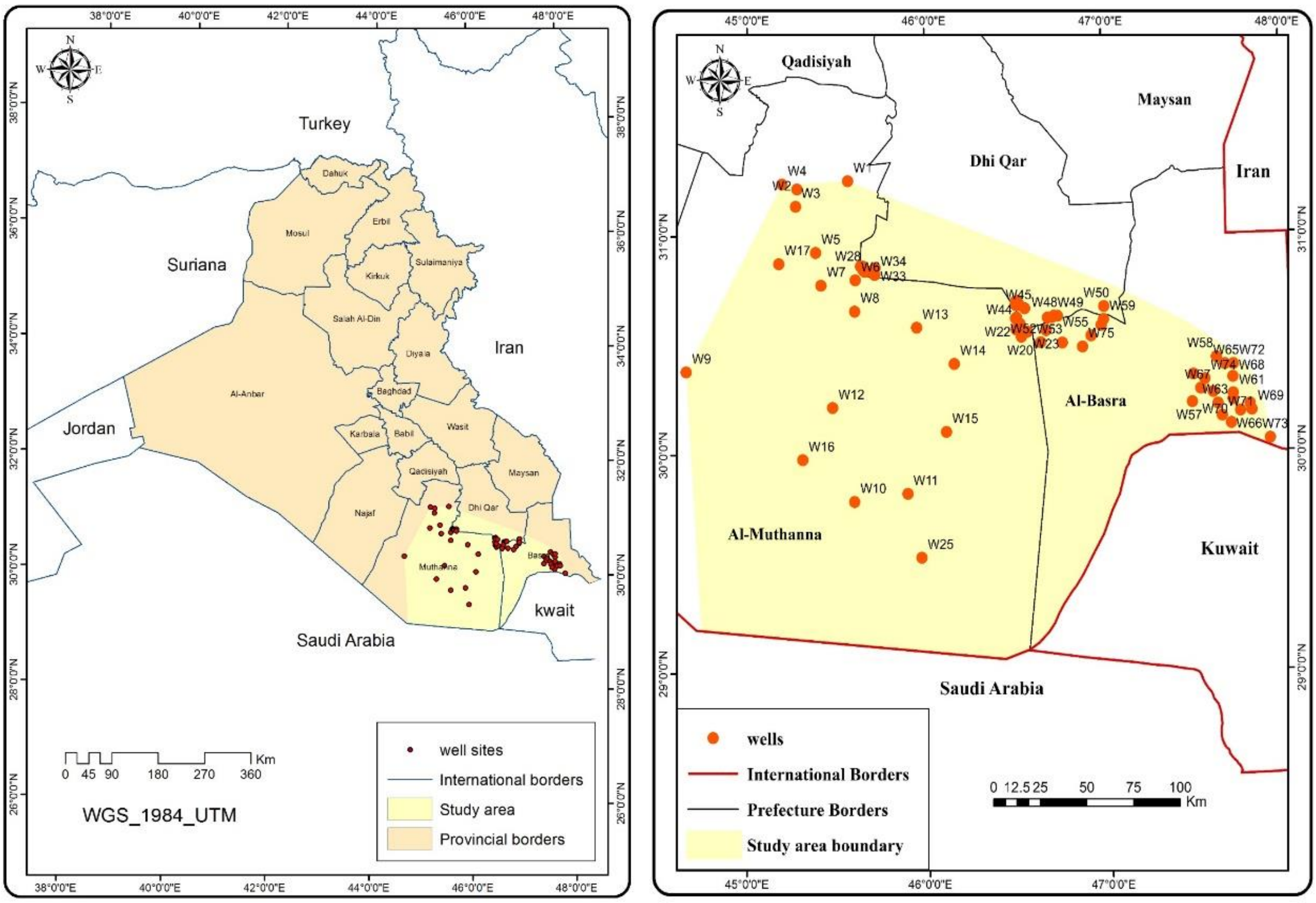


Figure 1. Location of the study area and samples distribution

2.2 Samples collection and water quality characterization

Groundwater samples were collected from 75 wells distributed over the entire study area. These wells are distributed into 25 wells within the administrative border of each governorate (i.e., the Governorates of Basra, Dhi-Qar, and Muthanna, which constitute the study area as described in section 2.1, and in Figure 1, the sequence of the locations of these wells was (1-25) within the borders of Muthanna governorate, wells (26-50) were within the borders of Dhi-Qar governorate, while wells (51-75) were within the borders of Basra governorate. These samples were collected and analyzed for two periods of the year 2020, i.e., wet periods in (January) and dry in (July), to sense seasonal changes in the characteristics of groundwater. 11 environmental parameters were measured for each well and each period. These measurements included pH (EC), TDS, and ion concentrations of K^{+}, HCO_3^{-}, Na^{+}, So_4^{-2}, Cl^{-}, Mg^{+2}, and Ca^{+2}. These environmental parameters were tested based on Iraqi water standards (IQS/417:2009) [26]. These comparisons aimed to determine the suitability of water in these wells for drinking uses, according to its acceptability with these standards; in addition, the spatial distribution of groundwater quality will be presented using GIS to study changes in water through sensitivity analysis for two time periods (wet and dry seasons).

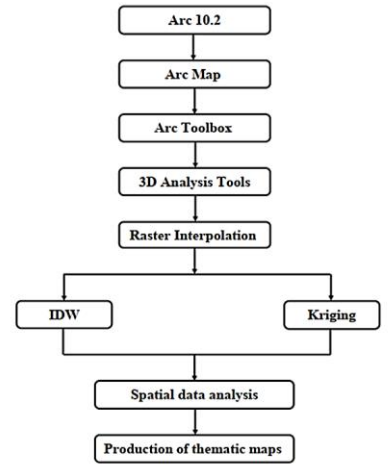


Figure 2. Flowchart of spatial modeling of GIS processing

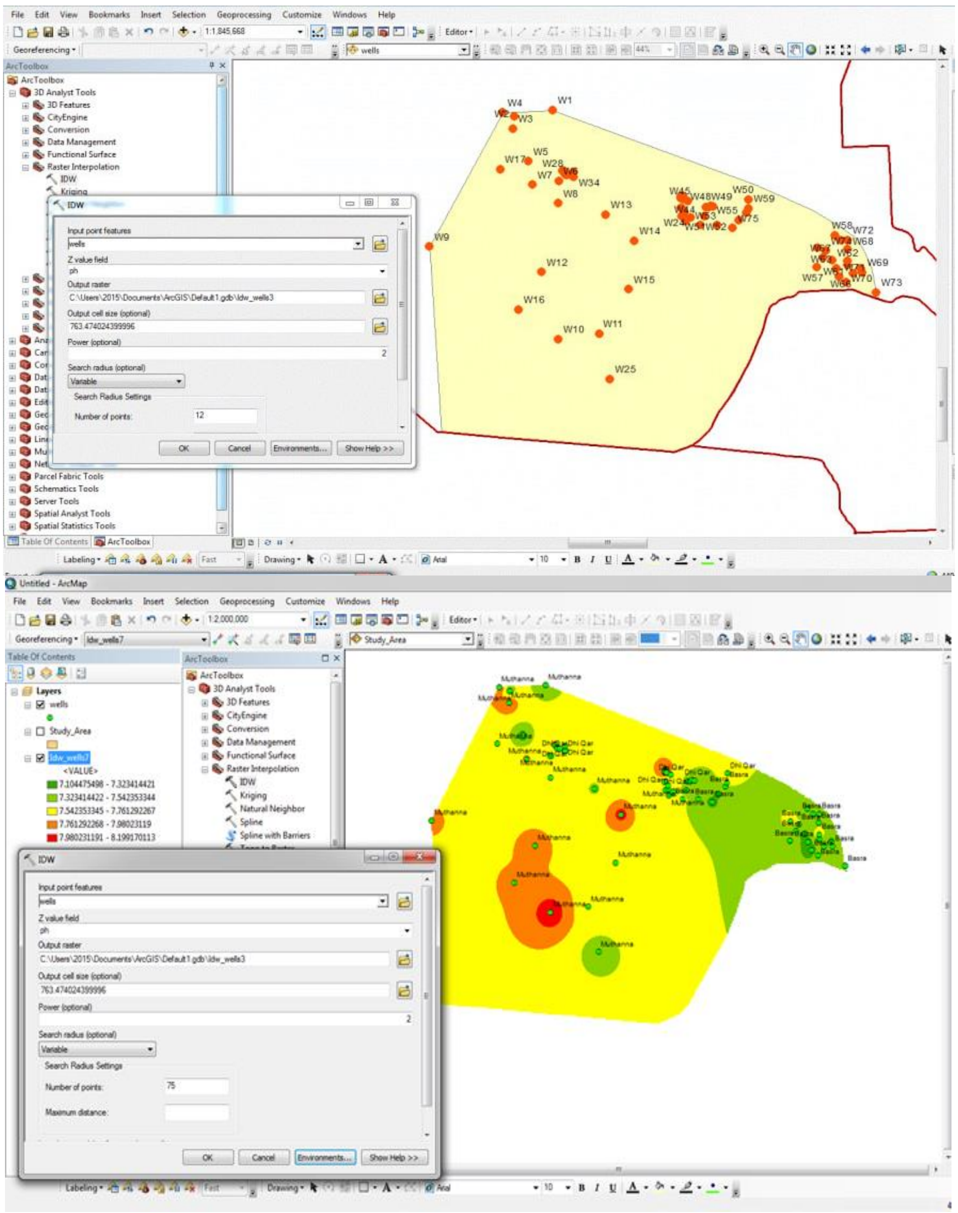


Figure 3. Performing IDW technique

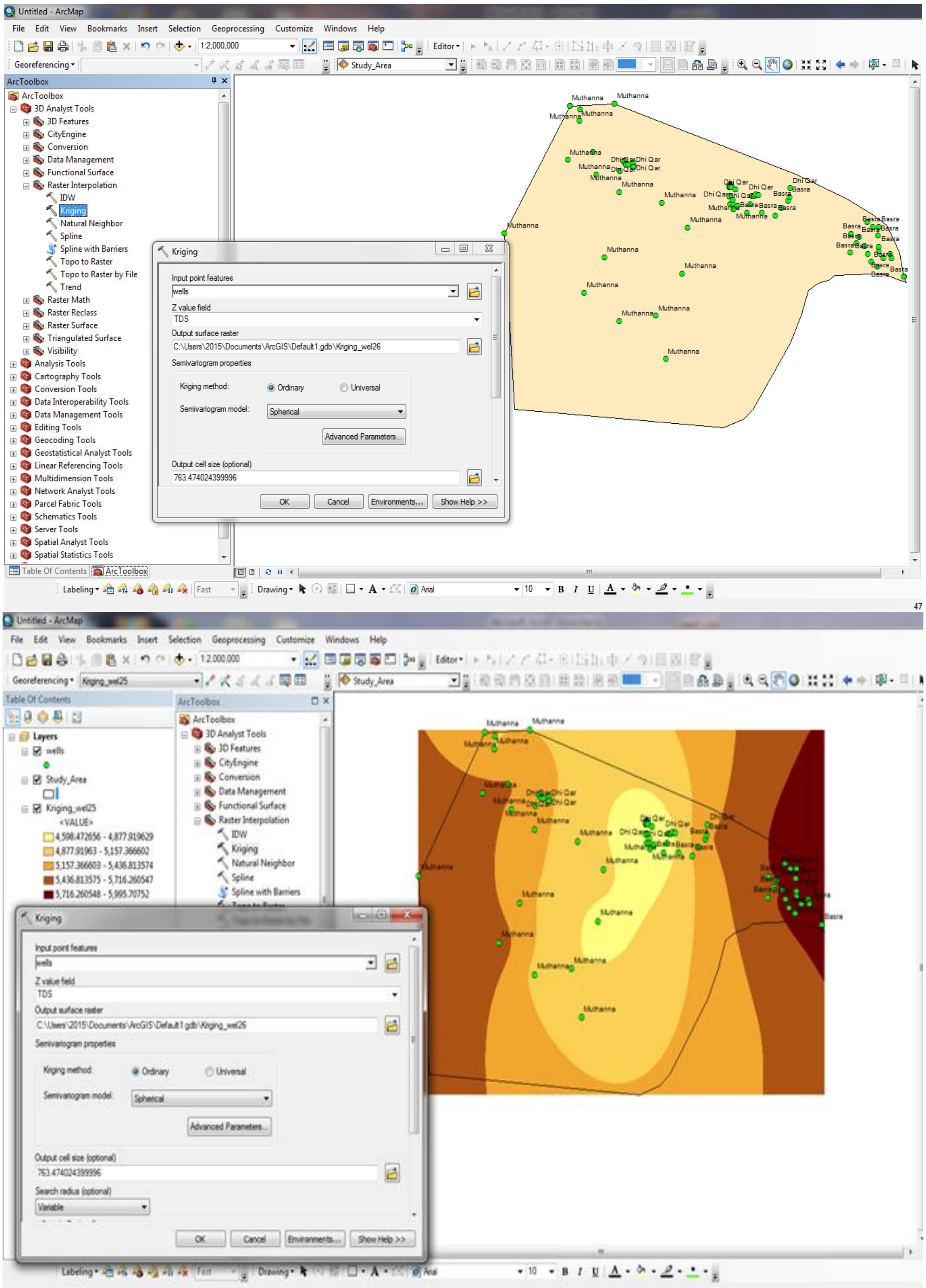


Figure 4. Performing Kringimg technique

2.3 Spatial modeling

Geographical information systems were used to build the spatial distribution of groundwater models. GIS models were constructed for groundwater wells that were distributed in the study area. The aim was to take advantage of the GIS capabilities to provide and create a database for the qualitative characteristics of groundwater and represent them in thematic maps. These models tried to detect and depict the seasonal variations of groundwater quality that occurred due to changes during the dry season (summer) and wet seasons (winter). After obtaining the descriptive data on the quality of groundwater in the study area, as the number of wells studied was 75 wells, the experimental results from the laboratory analysis measurements were taken for both seasons (summer and winter), as the data for each well was recorded according to its geographical location (X, Y) and the data was saved as an Excel sheet. After exporting the data from Excel to the Arc Map program, which is one of the Arc GIS 10.2 applications, to be saved in a special attribute table, and displayed in the program interface, the maps were output in two ways, the first method is Inverse distance weighted (IDW) and the second method is Kriging as in the Figures 2, 3 and 4, respectively. (IDW) interpolation available in the Arc GIS ® Geostatistical

Analyst toolbar. IDW interpolation is a method that is frequently employed in variable mapping. This method of interpolation is precise and convex, and it only suits the continuous model of spatial variation. Based on sites that are merely weighted by distance, this method was developed in mining and geological engineering to estimate the value of a variable in some new locations, the value from the known site is used. With a weighted linear combination set of sample points as its foundation, IDW interpolation relies on both statistical and mathematical techniques to build surfaces and determine forecasts for unmeasured locations.

3. RESULTS AND DISCUSSIONS

The characteristics of water quality vary greatly around the world. As a result, the quality of natural water sources used for various purposes should be determined in terms of the specific water-quality parameters that influence the potential use of water. The quality of groundwater is considered essential because it is the main factor in determining the suitability of this water for drinking and other purposes such as domestic, industrial, and agricultural [27, 28]. Therefore, this study highlights the water quality parameters of groundwater for distributed wells in the southwestern part of the Iraqi desert. The results showed the minimum, maximum, and average values of groundwater parameters for 75 well during wet and dry seasons. Tables 1 and 2 shows the study area's minimum, maximum, and average values of tested parameters for wet and dry seasons, respectively. Also, the acceptable thresholds for these parameters based on WHO [29] and Iraq drinking standards are listed in Tables 1 and 2. The spatial models for the tested parameters using GIS were depicted and discussed in the followed subsections.

Table 1. The minimum, maximum, and average values of tested parameters for wet season in the study area

Wet Season					
Parameter	**Minimum**	**Maximum**	**Average**	**WHO Standards**	**Iraq Standards**
EC (mS/cm)	1132	14036	7018.32	1500	2000
TDS (mg/l)	1256	10143	5082	1000	1000
pH	7.28	7.98	7.49	6.5–8.5	6.5–8.5
Ca (mg/l)	129	1152.4	547.34	200	125
Mg (mg/l)	98.5	445.6	204.35	50	50
Na (mg/l)	228.5	1100	599.34	200	200
K (mg/l)	15.2	103.1	39.28	12	12
HCO_3 (Alkalinty) (mg/l)	37.9	324.2	115.89	120	150
Cl (mg/l)	448.8	3732.7	1357	250	250
SO_4 (mg/l)	831	3218	1664	250	400

Table 2. The minimum, maximum, and average values of tested parameters for dry season in the study area

Dry Season					
Parameter	**Minimum**	**Maximum**	**Average**	**WHO Standards**	**Iraq Standards**
EC (mS/cm)	1016	12578	7157.55	1500	2000
TDS (mg/l)	1889	8992	5249.19	1000	1000
pH	7.1	8.3	7.72	6.5-8.5	6.5-8.5
Ca (mg/l)	168	1012.2	535.64	200	125
Mg (mg/l)	89.5	473	221.5	50	50
Na (mg/l)	206.3	1230	632.66	200	200
K (mg/l)	13.7	107	42.52	12	12
HCO_3 (Alkalinty) (mg/l)	44.6	231.2	107.63	120	150
Cl (mg/l)	542.9	3811.4	1426.8	250	250
SO_4 (mg/l)	1116	3018	1723	250	400

3.1 Modeling some inorganic indicators of groundwater samples

The spatial modeling of some tested inorganic indicators of groundwater included the electrical conductivity (EC), total dissolved solids (TDS), and pH, as illustrated in Figure 5. Figures (5-A1 and 5-A2) show the distribution of EC values with different groundwater ranges for both seasons, dry and wet. The maximum EC value reached 14036 mS/cm in the study area's western parts. Meanwhile, the central parts of the study area included the lower EC values. In general, the values of EC are higher than the acceptable limits of EC that should be recorded for drinking water compared to WHO and Iraqi drinking water standards. This means this water needs to treat before being used as drinking water. Total dissolved solids (TDS) concentration is proportional to electrical conductivity (EC; mhos/cm) or specific conductance. The conductivity of water measures its ability to transmit electrical current. Conductivity is a relative term, and the relationship between TDS concentration and conductivity varies depending on the water sample and TDS concentration range. As the concentration of TDS increases, so does the conductivity. Therefore, a similar trend for spatial distribution for TDS can be seen in Figures 5-B1 and 5-B2 that show the range of TDS values in the study area. pH is another indicator of water quality. The spatial distribution of pH values is illustrated in Figures 5-C1 and 5-C2, respectively. The pH values more than 7. This means the groundwater of these areas tends to be a little alkaline, especially in the western parts of the study area.

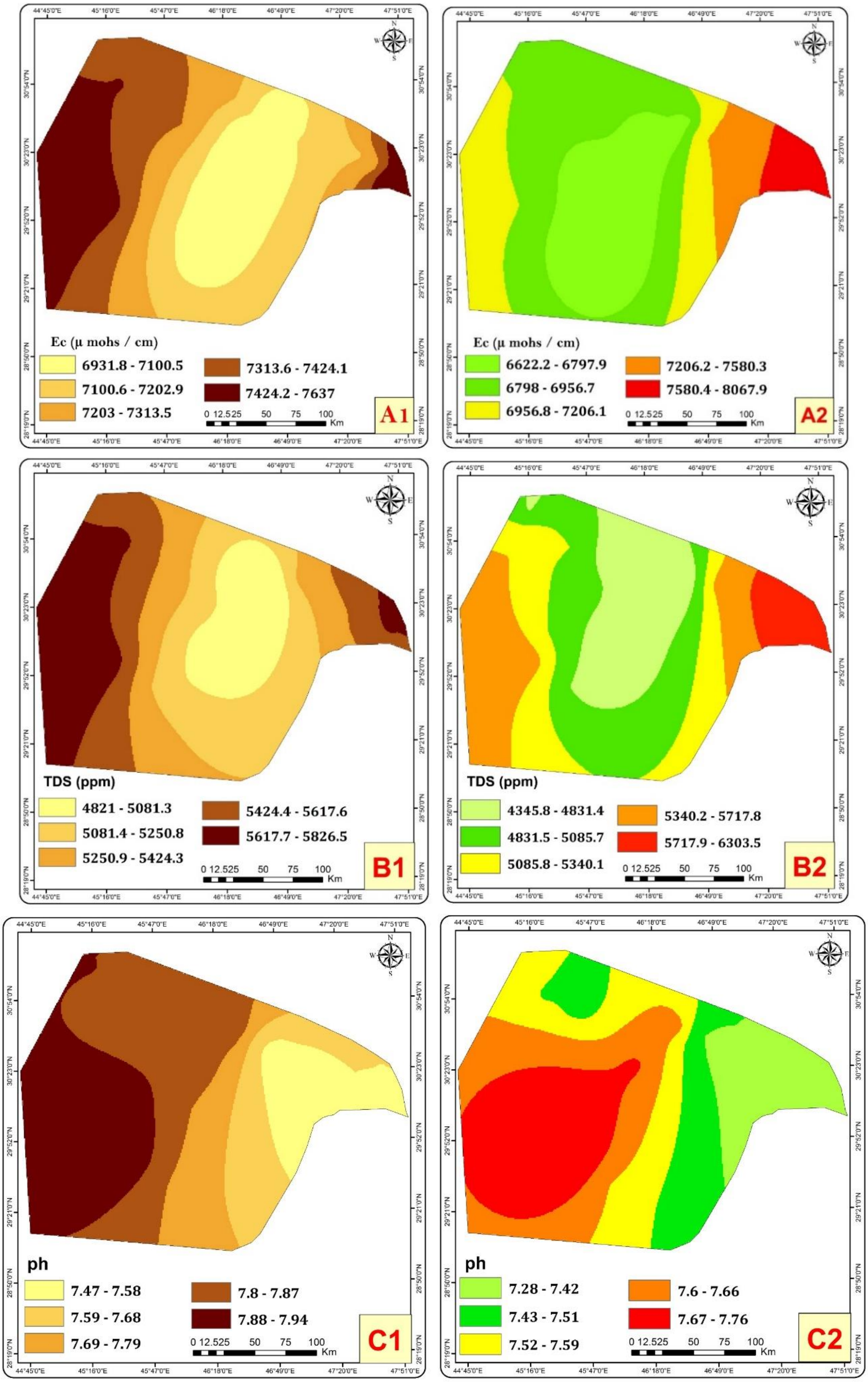
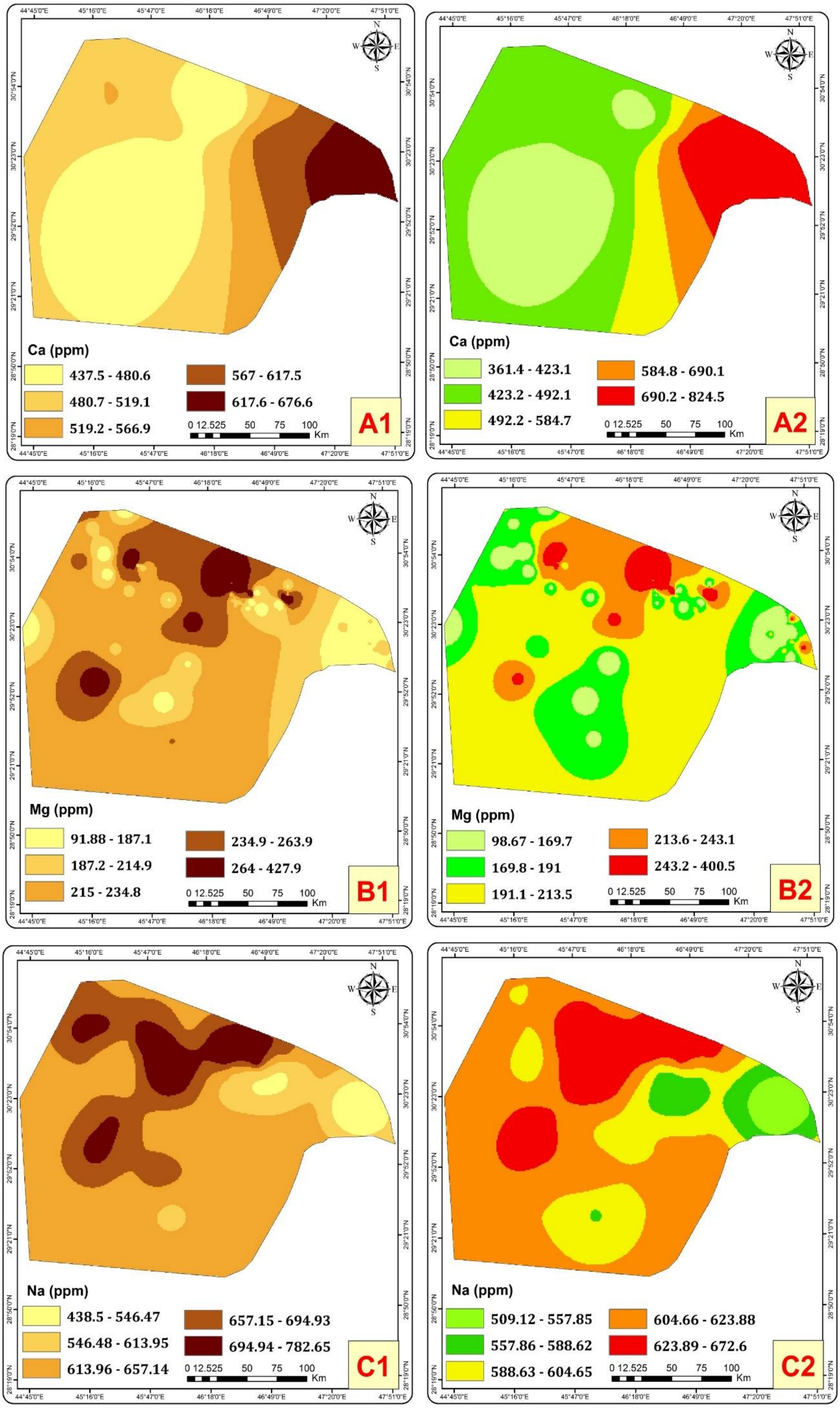


Figure 5. Spatial distribution for parameters of groundwater a) for EC, (A1) in the dry season and (A2) in the wet season; b) for TDS, (B1) in the dry season and (B2) in the wet season; c) for pH, (C1) in the dry season and (C2) in the wet season


Ca (ppm)
437.5 - 480.6
480.7 - 519.1
519.2 - 566.9
567 - 617.5
617.6 - 676.6
A1
Ca (ppm)
361.4 - 423.1
423.2 - 492.1
492.2 - 584.7
584.8 - 690.1
690.2 - 824.5
A2
Mg (ppm)
91.88 - 187.1
187.2 - 214.9
215 - 234.8
234.9 - 263.9
264 - 427.9
B1
Mg (ppm)
98.67 - 169.7
169.8 - 191
191.1 - 213.5
213.6 - 243.1
243.2 - 400.5
B2
Na (ppm)
438.5 - 546.47
546.48 - 613.95
613.96 - 657.14
657.15 - 694.93
694.94 - 782.65
C1
Na (ppm)
509.12 - 557.85
557.86 - 588.62
588.63 - 604.65
604.66 - 623.88
623.89 - 672.6
C2
0 12.525 50 75 100
Km

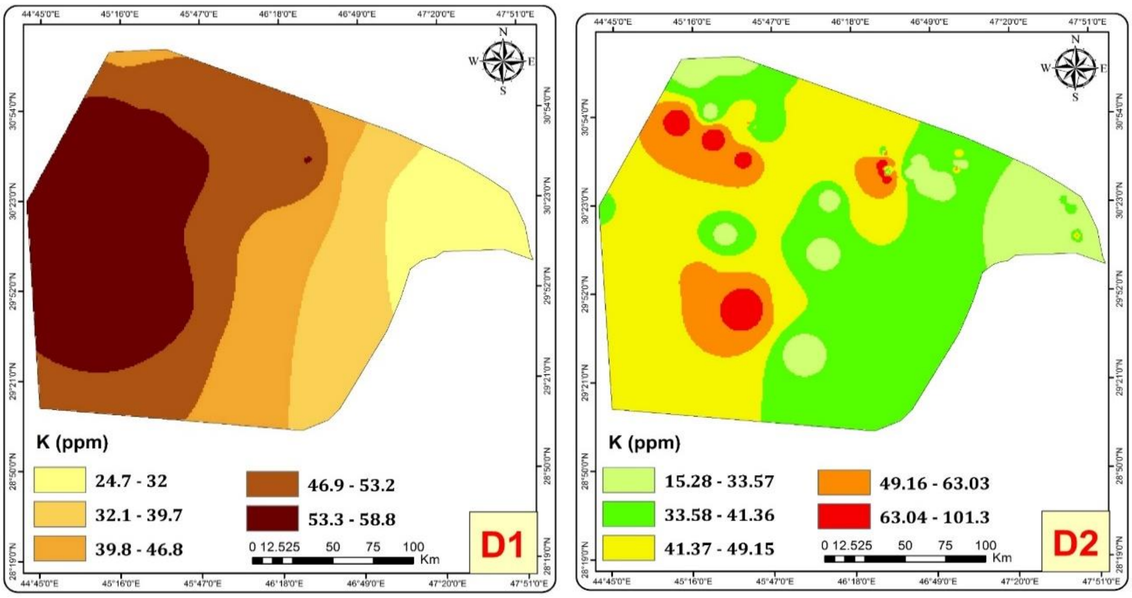
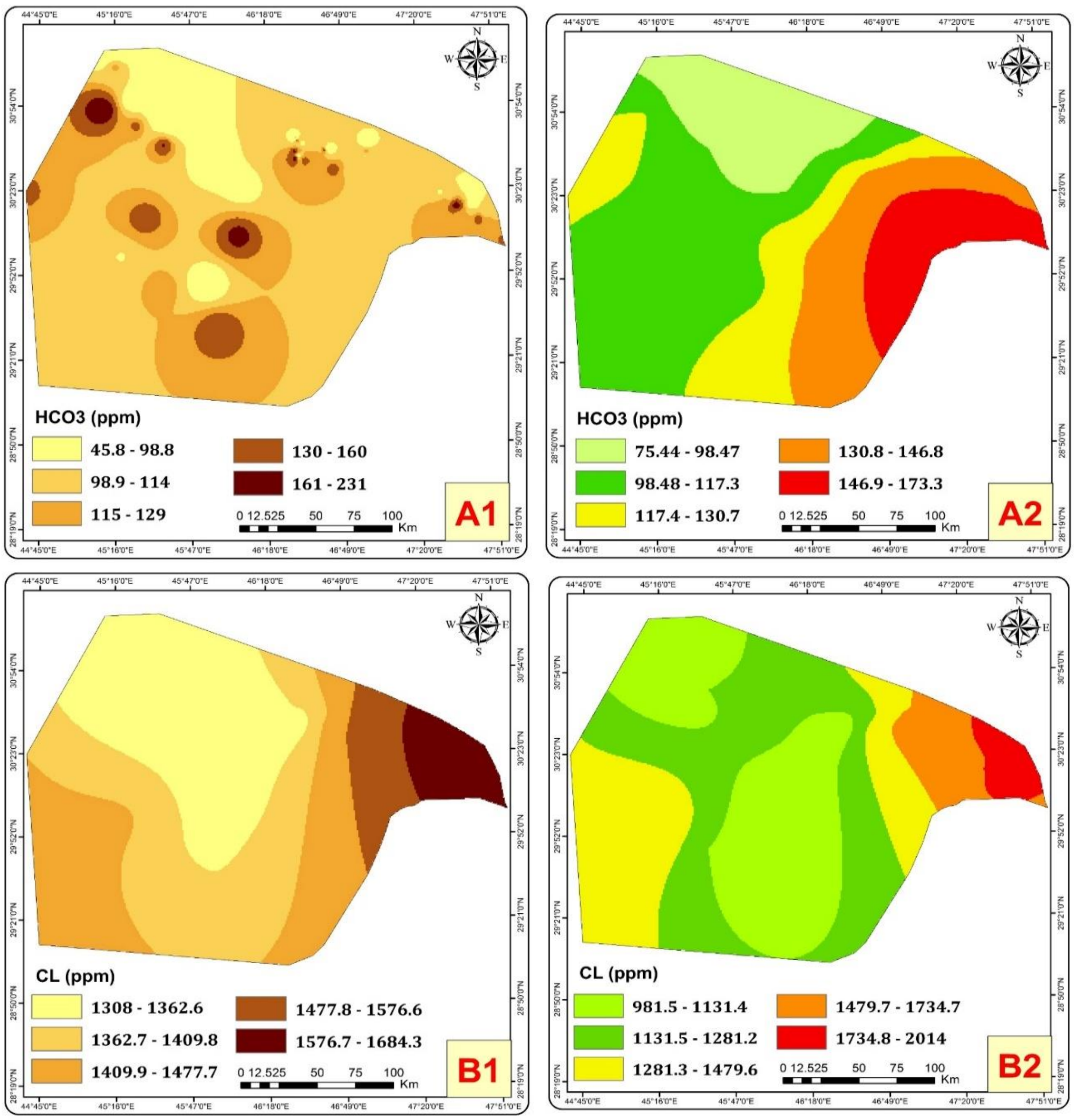


Figure 6. Spatial distribution for parameters of groundwater a) for Ca, (A1) in dry season and (A2) in wet season; b) for Mg, (B1) in dry season and (B2) in wet season; c) for Na, (C1) in dry season and (C2) in wet season; d) for K, (D1) in dry season and (D2) in wet season



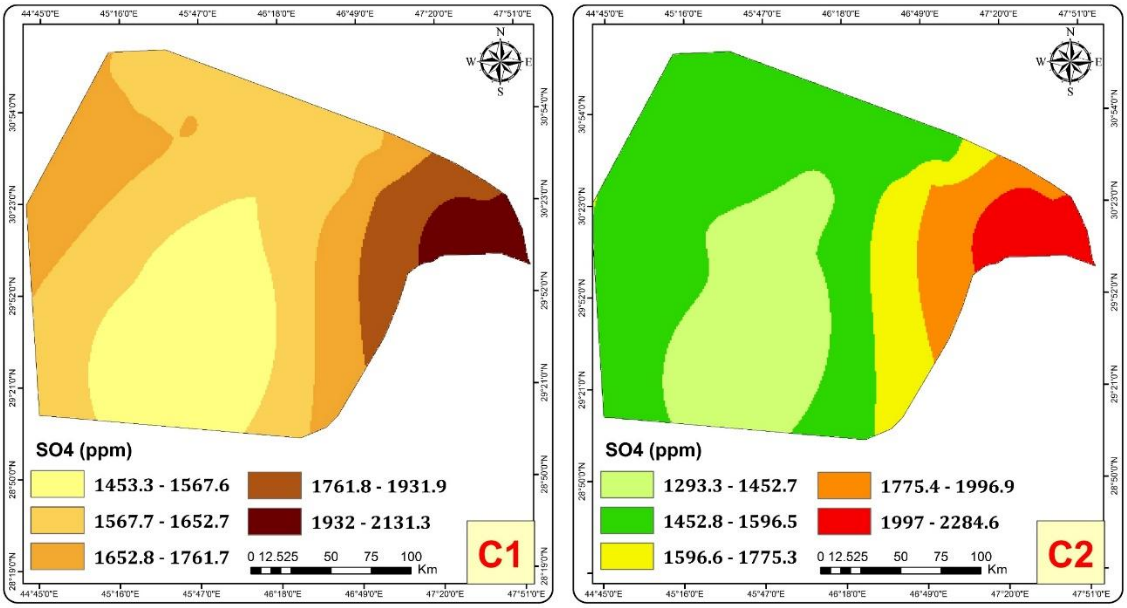


Figure 7. Spatial distribution for parameters of groundwater a) for HCO_3, (A1) in dry season and (A2) in wet season; b) for Cl, (B1) in dry season and (B2) in wet season; c) for SO_4, (C1) in dry season and (C2) in wet season

3.2 Major cations of groundwater

Calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) are the most common cations found in the groundwater. The most common cation in water is calcium (Ca). The primary concern about calcium stems from the fact that calcium is the primary cause of water hardness [30]. The results showed that Ca concentrations were higher during the wet season than in the dry season, as seen in Figures 6-A1 and 6-A2, respectively. The eastern parts of the study area showed the highest values of Ca with some seasonal variation. This may be attributed to the chemical transformations that result from the contact between soils, rocks, and water, especially during the runoff season. In general, the detected Ca concentrations are higher than the limit of Ca (125 ppm) recorded by Iraqi drinking-water standard IQS: 417/2009 and WHO standards.

Magnesium (Mg), unlike calcium, is not abundant in rocks. As a result, while magnesium salts are more soluble than calcium salts, water contains less magnesium. Mg can be another indicator of water hardness. The investigations during dry and wet seasons showed that Mg exceeded the threshold of acceptable concentration that should be found in drinking water as reported by IQS: 417/2009, which suggests 50 ppm, as seen in Figures 6-B1 and 6-B2, respectively. It is interesting to mention that the hardness correlates with TDS. It represents the total concentration of Ca and Mg ions. Therefore, the high concentrations of Ca and Mg ions make us interfere that the groundwater in the study area was hard and interference with soaps and dyes in cleaning. Sodium (Na) is an essential indicator of drinking water. The spatial model shows that Na had higher minimum levels during the wet season compared to the dry season for the same areas. Generally, the detected concentrations of Na in the study area along dry and wet seasons are much higher than the allowed levels that should be found in drinking water according to IQS: 417/, 2009, which should be no more than 200 ppm, as illustrated in Figures 6-C1 and 6-C2, respectively. Besides the previous cations, the study detected high concentrations of potassium (K) in the groundwater for the study area during both seasons compared to the thresholds of WHO and IQS: 417/, 2009, as mentioned in Tables 1 and 2. The spatial model of K was constructed and depicted in Figures 6-D1 and 6-D2 for dry and wet seasons, respectively.

3.3 Major anions of groundwater

One of the significant anions that are present in untreated natural water is bicarbonate (HCO_3). These ions play a crucial role in the carbonate system, which gives natural water a buffering capacity and is primarily responsible for the alkalinity of water [31]. The results showed that the bicarbonate level was lower during the wet season than in the dry season, as illustrated in Figures 7-A1 and 7-A2. This difference may have resulted in the runoff that may alleviate the HCO_3 levels in the groundwater [32]. Natural water also frequently contains anions like chlorides (Cl) and sulfates (SO_4), besides bicarbonates (HCO_3). These anions are released during geologic formations' dissolution and dissociation of common salt deposits. The concentration of chlorides anions (Cl) determines water quality because increasing the concentration of these anions causes water quality to deteriorate, limiting the ability to use natural water for various purposes.

The main source of chlorides anions (Cl) in natural water is magmatic rock formations containing chlorine-containing minerals. The second source of this anion is the Ward Ocean, where a considerable amount of chlorides anions (Cl) enter the atmosphere [33]. Then, chloride anions (Cl) transfer from the atmosphere to the natural water via the interaction between soil and precipitations. The spatial model based on Cl detected samples is illustrated in Figures 7-B1 and 7-B2 for dry and wet seasons, respectively. The results showed that the levels of Cl of both seasons were much higher than the acceptable limit (250 ppm) that should be found in drinking water according to WHO and IQS: 417/2009. For instance, the average level of Cl in wet and dry seasons was 1357 ppm and 1427 ppm, respectively. The highest Cl concentrations were found in the eastern parts of the study area. Sulfates (SO_4) are frequently found in natural water due to a chemical dissolution, dissolving sulfur-content minerals and oxidising sulfates and sulfur. The sulfates anions (SO_4) enter natural water due to the oxidation of the substances of plant and animal origin. The increased concentration of the sulfates anions (SO_4), on the one hand, brings about change for the worse of some physical characteristics of water (taste, smell, etc.) and has a destructive influence on human consumption [34]. Based on WHO and IQS: 417/2009 water specifications, the concentrations should be no more than 400 ppm and 250 ppm, respectively. While the investigations showed that the groundwater of the study area included higher levels of SO_4 for dry and wet seasons, as illustrated in Figure 7-C1 and 7-C2, respectively.

4. CONCLUSION

People in the Iraqi desert use wells as the basic source for supplying drinking water. For this reason, identifying the quality of the groundwater and modeling the distribution of the water quality parameters could help people and authorities ease groundwater usage. This study showed that the groundwater quality is currently unsatisfactory for drinking purposes based on WHO and Iraqi national specifications. The study constructed maps for water quality parameters in a selected area of the Iraqi desert via spatial GIS models. These models showed the range of water quality parameters during dry and wet seasons which facilitate selecting the sources and type of water treatment. As a further research recommendation, it is important to evaluate the groundwater in the study area for irrigation and industrial purposes. Moreover, performing the statistical analysis can facilitate understanding the groundwater quality variation. As a further study, it is recommended to utilize the study results and evaluate the groundwater in the study area for irrigation and industrial usage. Furthermore, the spatial model can be extended to model the soil properties to identify the soil's suitability for agricultural purposes.

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