Research Article

Monitoring the Impact of Changes in Groundwater Quality Indicators in Western Karbala on Wheat Growth using Sentinel-2 Data

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Abstract | Groundwater in the last decade is used to study the possibility of wheat agriculture in the desertification of the west of Kerbala/Iraq. The aim of this study was to estimate the changes detected in the groundwater level which indicates the wheat growth for the period of the study. Sentinel-2 data can be used to monitor this change using Normalized Difference Vegetation Index (NDVI). The results of this study showed that there are significant differences in the NDVI values within wheat growth season in the ROI. Since the maximum significant increase in (March, February, January, and December), respectively. The results showed a very poor wheat yield within the seasonal growth progress; this is suitable with the groundwater nutrient growth by rains? While most of the east part from ROI classified as fair following by good, the last is the dominant in the march 2024. Also, there is three types of salinity stable ECw these are (Good, Fair, and Poor furthermore the Verypoor) class also appear only in the December 2023. There is a contrast in the groundwater salinity values. The effects of the groundwater salinity in the NDVI indices produce that R^2 = 0.86, R^2 = 0.85 in inverse relation. The negative effect to the salinity concentration in the wheat health in the ROI. The conclusion of this study is that the disappear of good class in the period (December 2023, and January 2024) respectively for SARw furthermore Poor class disappear in (February, March)/ 2024 respectively. SARw dominant for fair class with values in the (December 2023, (January, Ebrary, March)/ 2024) is (36.85%, 64.60%, 87.06%, 94.90%) from ROI respectively. The results indicated that most of the groundwater suitable in the irrigation region especially in wheat growth season.

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Keywords | Groundwater, NDVI, IDW, SAR, ECw

Introduction

Wheat is one of the most important cereal crops in the world. It produces with sufficient quantities, which contributes to provide the basic food requirements for the growing population. Wheat grains in diet meets the nutritional needs. Its important role in the national economy is to promote international trade (Shewry and Hey, 2015). Developing the ability to produce wheat at a high level contributes to achieving accreditation. Self-state food supply. Instead of relying on wheat imports from abroad, the country can rely on its local production to meet the needs of its population and maintain independence in the food sector (Al-Waeli *et al*., 2020). According to the scarcity of rainfall in ROI the wheat production projects depend on groundwater as essential source for irrigation. Because of the wheat production importance many studies achieved to study this product, its study, and analysis statistics in order to ensure its sustainability for us.

The hydro chemical tests for groundwater care to take into consideration because it's related to decision maker useful for agriculture in the country (Khudair *et al*., 2022).

The importance by the groundwater characteristics which indicates the irrigation suitable require monitor the effects of these waters in the vegetation health state for this reason the health state for this reason the helpful by remote sensing data and the spatial indices NDVI was important to achieve this goal (Al-Waeli *et al*., 2024).

This study aims to achieve geospatial assessment for groundwater status and to integrate it with NDVI which derived from Sentinel-2 data to distinguish hydro chemical characteristics effects in wheat health status which agriculture in this region.

Materials and Methods

The study region

This study conducted in the west of Karbala, Iraq (Latitudes 32°20'54.1500"N to 32°27'37.4362"N and longitude 43°26'36.8826"E to 43°38'04.3786"E) on an area of 15414.363441 hectare. Thirty groundwater samples were collected and their coordinates fell depends on Global Navigation Satellite System (GNSS) and are shown in Figure 1.

Digital processing for Sentinel-2 data

Sentinel-2 data download from https://dataspace.copernicus.eu/site. Four images was download from this site as the following:

1-In7/12/2023:S2A_MSIL1C_20231207T075311_N0509_R135_T38SLA_20231207T083526.SAFE

2- 16/1/2024: S2A_MSIL1C_20240116T075241_N0510_R135_T38SLA_20240116T083811.SAFE

3- 5/2/2024: S2A_MSIL1C_20240205T075121_N0510_R135_T38SLA_20240205T083617.SAFE

4- 6/3/2024: S2A_MSIL1C_20240306T074801_N0510_R135_T38SLA_20240306T084041.SAFE

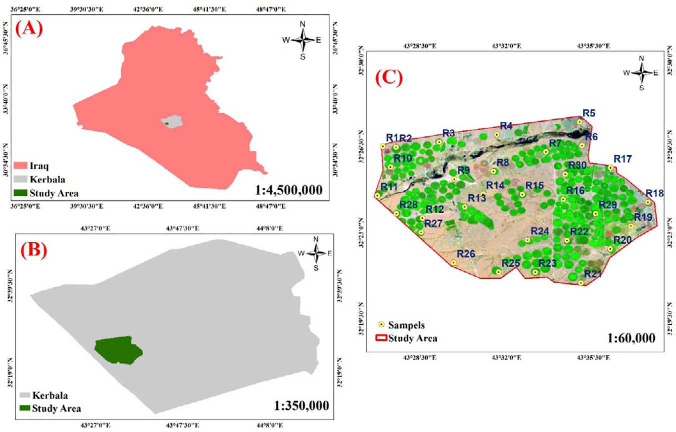

Figure 1: *A, Region of interest (ROI) in relation to Iraq; B, ROI in Karbala Governorate; C, Distribution pattern (soils and groundwater) samples.*

Radiometric calibration achieved; and the atmospheric effects removed using ENVI 5.6 (Fast Line of Sight Atmospheric Analysis of Spectral Hypercube Model) FLAASH model (Wu *et al*., 2013) then the Normalized Difference Vegetation Index (NDVI) measured using Equation 1 (Rouse et al., 1973) as in the following:

$$NDVI = \frac{[NIR - Red]}{[NIR + Red]} \;....(1)$$

Laboratory tests

Laboratory test for groundwater characteristics: Groundwater samples filtered; all salt measurement TDS achieved; the electric conductivity ECW also measured using EC- Meter, and the groundwater PH measured using PH-Meter furthermore measurement of (Calcium and Magnesium) dissolved in groundwater by Titration method (Sodium and Potassium) dissolved in groundwater measured using Flame photometer (Estefan *et al*., 2013).

Groundwater quality indicator

Groundwater quality indicator and its suitability for irrigation depends chart suggested by Johnson and Zhang (2009) as in Figure 2.

Figure 2 shows the quality and suitability of groundwater for irrigation according to Johnson and Zhang (2009).

In addition to the values of groundwater ECW which is measured in the laboratory, Sodium adsorbed in the groundwater rate (SARw) also calculated using Equation 2.

$$(SARw) = \frac{Na^{+}}{\sqrt{\frac{(Ca^{+2} + Mg^{+2})}{2}}} \quad \dots (2)$$

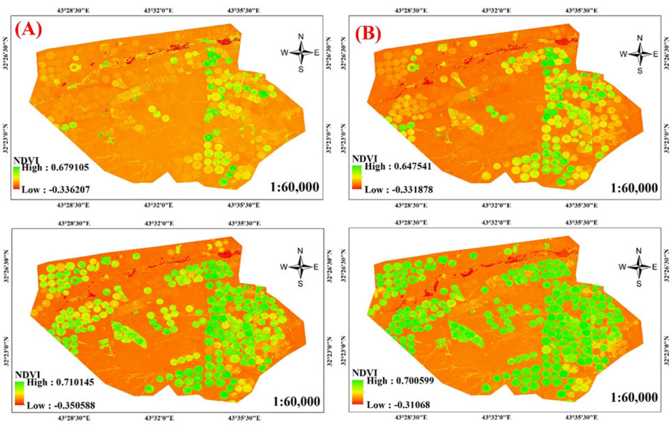

Figure 2: *A, NDVI values in December 2023; B, NDVI values in January 2024; C, NDVI values in February 2024; D, NDVI values in March 2024.*

The percentage of dissolved sodium in groundwater (Na%) also calculated from Equation 3.

$$\text{Na \%} = \frac{(\text{Na}^{+}) + (K^{+})}{(Ca^{+2}) + (Mg^{+2}) + (\text{Na}^{+}) + (K^{+})} * 100 \quad \dots (3)$$

Geostatistical analyst

Geostatistical analyst done using Inverse Distance Weight Method (IDW) by ArcGIS. Pro. V3.0.1 as in Equation 4:

$$Z(x) = \frac{\Sigma(W_i * Z_i)}{\Sigma(W_i)} \quad \dots (4)$$

Where Z(x) is the estimated value at the unsampled location x, Z_i is the value at the ith sample point, W_i is the weight assigned to the i^{th} sample point based on its distance to x.

While the maps for the descriptive values of groundwater indicator achieved using IDW (Al-Waeli *et al*., 2021).

Statistical analysis

To choose the changes for four periods (December 2023; January 2024; February 2024; and March 2024) between the study properties. Test of least significant difference achieved using GenSTAT12 and SPSS2026 according to (Al-Waeli and Aurass, 2020). All the charts drawn using excel 365 and the simple regression relations tested between the groundwater and NDVI values.

Types of groundwater quality indicators

Groundwater quality indications classified depends on (Moss and Kress., 2016) as in Table 1.

Normalized difference vegetation index (NDVI)

Figure 2 shows a clear difference in the wheat growth status since it was in lowest state in December 2023 (Figure 2A) and it was in the highest state in March 2024 (Figure 2D) this attributed to irregularity in the period of wheat agriculture in ROI; and the vegetation density appears in the (east and west north) of the ROI while the middle of the ROI still in the preparation phase for drilling additional wells to agriculture this leave and unexploited region. Also, there is more regions irrigated using center-pivot sprinkler systems have lowest NDVI values; for this reason, this important spectral indicator chosen to achieve this study to determine and studies the reasons of this problem to process and treatment it.

Table 1: *Salinity and SARw according to (Moss and Kress, 2016).*

Management	Classification	ECw micromhos
None	Excellent	< 500
Little concern, especially with periodic rainfall	Good	500-1500
Leach salts from soil as needed	Fair	1500-3000
Routinely leach; monitor soils	Poor	3000-5000
Requires special attention; consult water specialist	Very Poor	5000-6000
Do not use	Unacceptable	> 6000
Management	Classification	SARw
None	Excellent	< 1
Little concern; add pelletized gypsum periodically	Good	1 - 2
Aerify soil, sand top dress, apply pelletized gypsum, monitor soils	Fair	2 - 4
Aerify soil, sand top dress, apply pelletized gypsum, monitor soils closely, leach regularly	Poor	4 - 8
Requires special attention; consult water specialist	Very Poor	8 - 15
Do not use	Unacceptable	> 15

Table 2: *Descriptive statistics of NDVI.*

	N	Range	Minimum	Maximum	Mean		Std. deviation
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Dec-2023	30	0.305	0.034	0.338644	0.112625	0.0126	0.068888
Jan-2024	30	0.554	0.0404	0.59415	0.21541	0.0296	0.1618
Feb-2024	30	0.5995	0.054	0.65395	0.41514	0.0414	0.227
March-2024	30	0.611	0.06004	0.67101	0.4796	0.043761	0.2397
Valid N (listwise)	30						

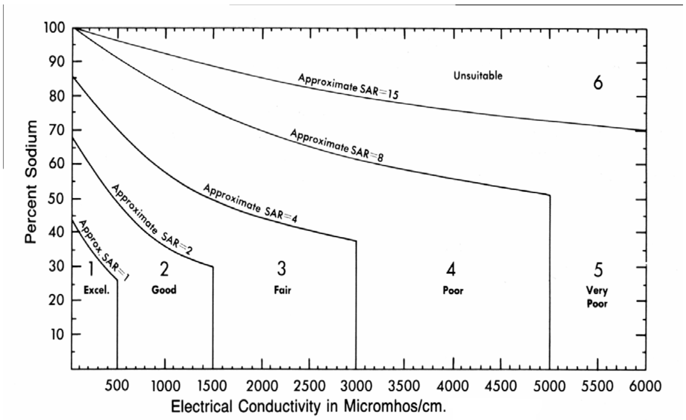

Figure 2: *The quality and suitability of groundwater for irrigation according to Johnson and Zhang (2009).*

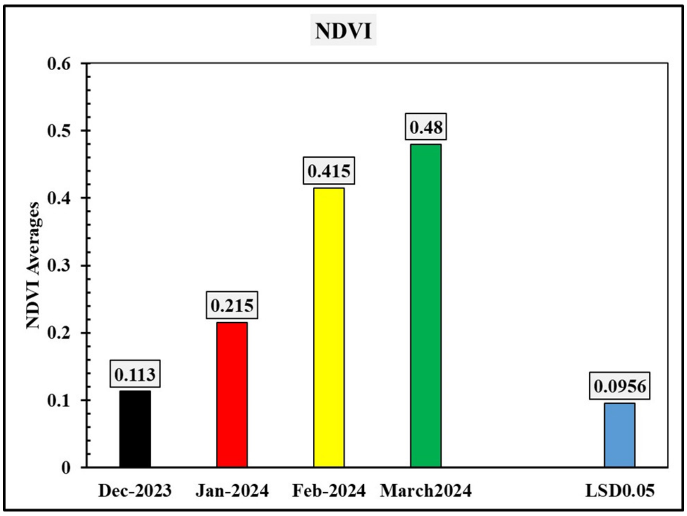

Figure 3: *Contrast significant between NDVI values in ROI.*

There is a contrast between the values of NDVI as shown in Table 2 and Figure 3; with significant difference and continuity of the wheat growth in ROI. It reaches higher significant value in NDVI values for the period (March and February/ 2024) respectively then January 2024 and December 2023. which indicate the important of estimating vegetation cover status; which support the aim of this study to agricultural area. This aim agreed with (Mohammed *et al*., 2018; Al-Helaly *et al*., 2022) this study investment using Sentinel-2 data and achieving sustainable development goals.

Groundwater quality in the study area

Figure 4 shows that the very poor class which was existence (Figure 4A) is disappear with the progress of season growth which is suitable to groundwater nutrient period by the sources of rains furthermore notice that most of the east part from ROI essentially classified as Fair followed by good class which is dominant in February (Figure 4C).

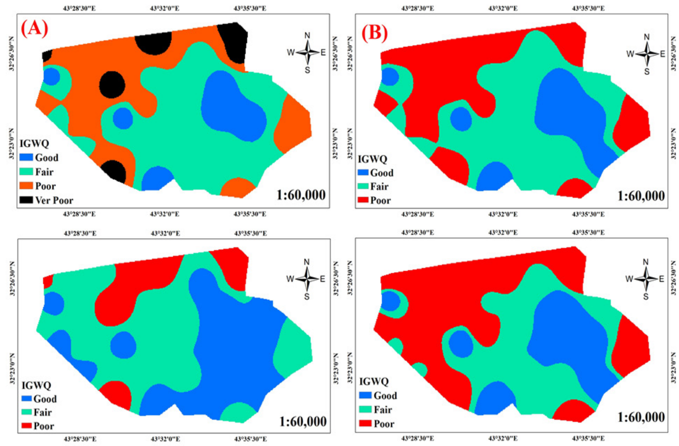

Figure 4: *S, Groundwater quality and suitability for irrigation in December 2023; B, Groundwater quality and suitability for irrigation in December January 2024; C, Groundwater quality and suitability for irrigation in February 2024; D, Groundwater quality and suitability for irrigation in March 2024.*

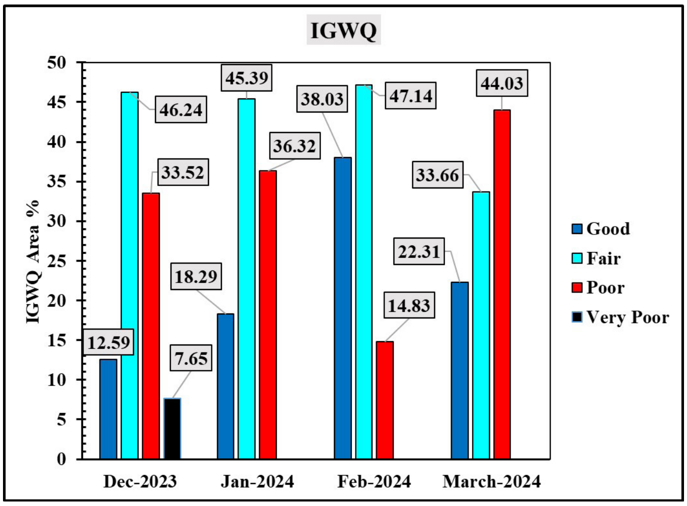

Figure 5: *Hundred percentage for groundwater quality areas and its suitability for irrigation.*

Figure 5 showed that good class was in its highest values in February 2024 since it records 38.03% and covered the lowest area in December 2023 since it was 12.59% from ROI while Fair class was in near percentage equal (46.24%, 45.39%, and 47.14%) for (December 2023, January 2024, February 2024) while it decreased in March to 33.66% from ROI.

Poor class increased from 33.52% in December 2023 to 36.32% in January to decreases significantly in February to 14.83% then it increase clearly in March 2024 to 44.03% with the increase in temperature and with the peak of water consumption in all cases this maintained of Fair class contribute in making the study region is continuity in agriculture activity but there is a suggestion to decision maker to take into consideration it is wrong to irrigate in the periods that groundwater far from (Good and Fair) class and prevent farmers from do that.

The understanding of groundwater suitability required understanding for essential indicators contrast spatially the salinity and SAR, Al-Waeli *et al.* (2021) mentioned that the effect of these indicators by the salinity concentration in it and these effects clear in the desert areas from Karbala furthermore the continuity attrition for groundwater clearly contribute in soil concentration increase in its which case bad type of it and in suitable for irrigation. The groundwater ionic component with highest concentration from (Calcium and Magnesium) had clear affect in decay of Sodium activity because of intense competition between Magnesium and Sodium on chlorides the last allows by precipitating a large amount of magnesium chloride salt.

Khudair *et al.* (2022) showed that the Sodium Adsorption Rate (SAR) in groundwater is important in indicating its suitability for irrigation, as its decrease enhances the reliability of irrigation with water that does not cause problems in the agricultural environment. Therefore, monitoring dissolved sodium concentrations is one of the tasks of the irrigation official to avoid soil deterioration and a decline in the yield of economic plants.

Groundwater salinity ECw

Figure 6 shows groundwater salinity distribution in ROI; its shows that their classes are equilibrium these are (Good, Fair, Poor) while the class very poor also appear only in December 2023 (Figure 6A). Figure 7 the hundred percentage for the distribution of these classes as follows 1.45%, 56.94%, 39.75%, 1.86% for Good, Fair, Poor, very poor, respectively through December 2023 to became 2.16%, 60.80%, 37.04%, for good, fair, and poor, respectively through January 2024 then 32.56%, 44.01%, 23.43% for Good, Fair, Poor through February, respectively to return to the same arrangement in January 3.33%, 69.48%, 27.19%, for good, fair, and poor class, respectively in March 2024.

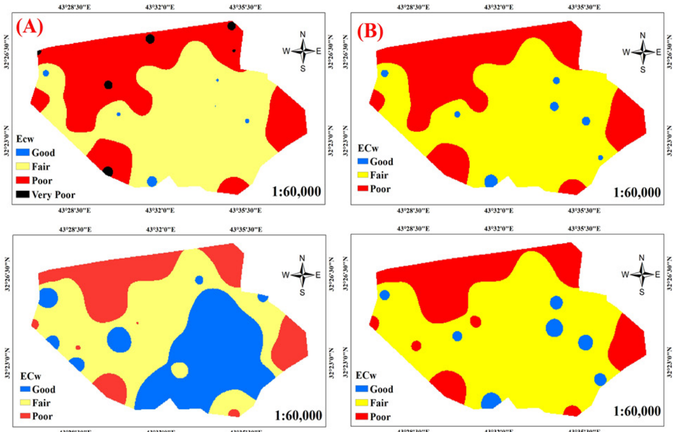

Figure 6: *A, Groundwater salinity in December 2023; B, Groundwater salinity in January 2024; C, Groundwater salinity in February 2024; D, Groundwater salinity in March 2024.*

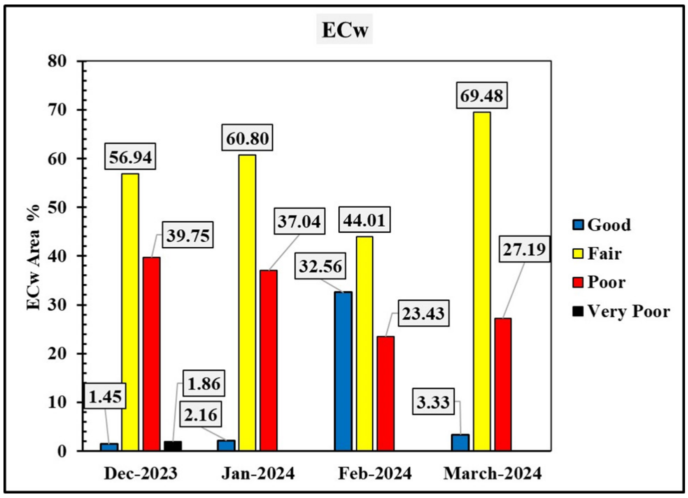

Figure 7: *Hundred percentage for groundwater salinity class areas.*

Table 3 shows that the existence of groundwater salinity values differences and Figure 8 shows the descriptive statistics which appears the salinity increases significantly in December 2023 and January 2024 compared with February 2024 which have lowest values of salinity equal to 1896 Micromhos classified under Fair class for this reason it is suitable for irrigation. All of these according to the oscillation in climate changes likes the raining in January and February allows to increase water sources in this

Table 3: *Shows the descriptive statistics of ECw.*

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Dec-2023	30	3867	1332	5199	3119.90	257.748	1411.746	1993026.507
Jan-2024	30	3669	1280	4949	2980.77	245.297	1343.547	1805117.426
Feb-2024	30	2342	812	3154	1896.23	156.351	856.372	733373.220
March-2024	30	3341	1158	4499	2704.43	223.005	1221.448	1491935.978
Valid N (listwise)	30							

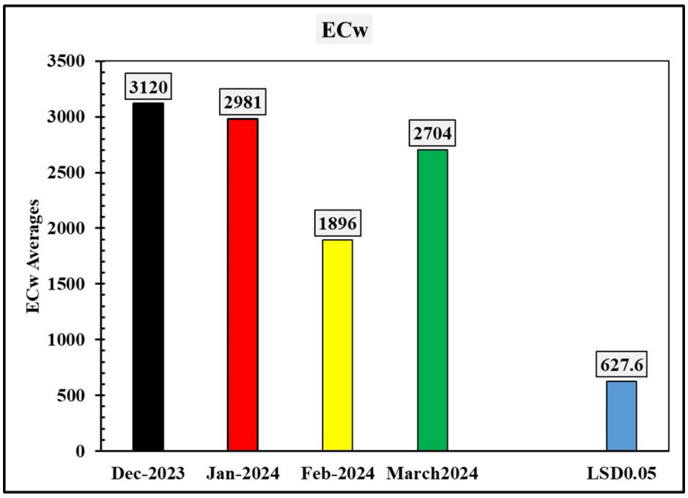

Figure 8: *The variation significance between groundwater salinity rates in ROI.*

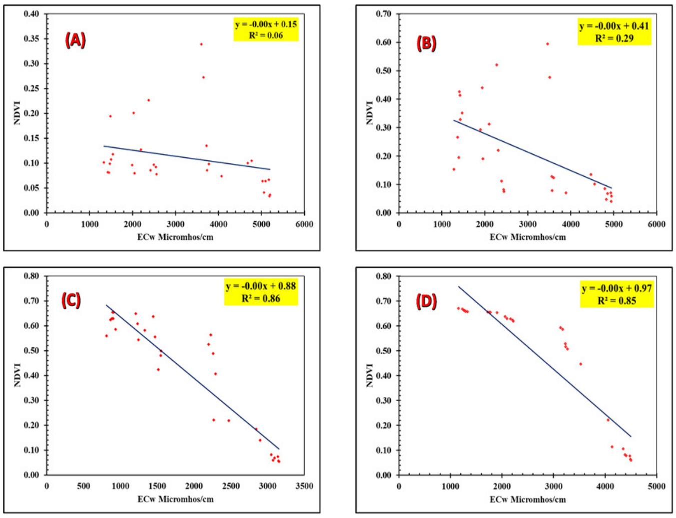

Figure 9: *A, Simple linear regression between salinity and NDVI values in December 2023; B, Simple linear regression between salinity and NDVI values in January 2024; C, Simple linear regression between salinity and NDVI values in February 2024; D, Simple linear regression between salinity and NDVI values in March 2024.*

period compared with others which cause salinity decrease and it is the end of draught season and winter starts. The increases result from the effects of the dry season and high evaporation rates that extend for more than nine months in the study area, which is desert in nature.

Awadh et al. (2021) mentioned in their study to the effect of human activity on salinity increase in the groundwater since sewage drainage and chemical agriculture lead to a significant increase in groundwater salinity concentrations, so the salinity in groundwater increases during periods of intense human activity.

Rajmohan *et al.* (2021) proved that dry climate reached in activity to aquifer which cause delayed rainfall and high evaporation rates lead to high levels of groundwater salinity, but it may decrease when high quantities of water are available, especially in the rainy season, which gives a characteristic of salt fluctuation, especially to groundwater in desert areas.

Figure 9 shows that the effects of groundwater salinity on wheat health status index (NDVI) produced a coefficient of determination of $R^2 = 0.86$ in February 2024 and a coefficient of determination of $R^2 = 0.85$ in March 2024, with a negative relationship, which confirms the negative impact of high salt concentrations on the health status of wheat in ROI. The lack of clarity of the relationship in the months of December 2023 and January 2024 may be attributed to the fact that the growing plant was not subject to the effects of irrigation water salinity, due to the weakness of the vegetation cover in these two months and their lack of clarity and completeness when the plant advances in its growth, and In our study, we find that understanding the relationship between groundwater salinity and the vegetation cover index can provide valuable information about the effect of salinity on vegetation dynamics and guide sustainable water management practices. High levels of salinity negatively affect the strength of vegetation cover. The study emphasizes the importance of monitoring and managing groundwater salinity to maintain healthy ecosystems and sustainable agriculture. Al-Waeli *et al.* (2024) believe that the reason for the deterioration of vegetation cover in Karbala, Iraq, during recent decades is indicative of the deterioration in NDVI values due to following wrong policies using sources of unknown quality. For irrigation or irrigation without providing an effective drainage system, it allows salts carried with groundwater to accumulate on the surface of the soil over time, causing poor plant health and a clear shrinkage of agricultural areas in the last ten years.

Sodium adsorption rate in groundwater (SARw)

Figure 10 shows that absence of good class in December 2023 and January 2024, which indicates a rise in sodium concentrations in groundwater compared to the concentrations of calcium and magnesium. When the temperature decreases, which is often accompanied by the dissolution of oxygen compounds, the absence of the Poor class is noted in February 2024 and March 2024, as the abundance of dissolved calcium causes a state of ionic balance in which the effectiveness of dissolved sodium in groundwater is inhibited during this period. Figure 11 also shows that the Poor class occupied 63.15% and 35.40% of the area of the study area for in December 2023 and January 2024 respectively. As for the good class, it occupied 12.94% and 5.10% of the area of the study area for the months of February 2024 and March 2024, respectively. The dominance was for the Fair class, which occupied 36.85%, 64.60%, 87.06%, and 94.90% of the area of the study area during December 2023, January 2024, February 2024, and March 2024, respectively, which indicates the suitability of a large portion of the groundwater in the region for irrigation, especially in the wheat growth season.

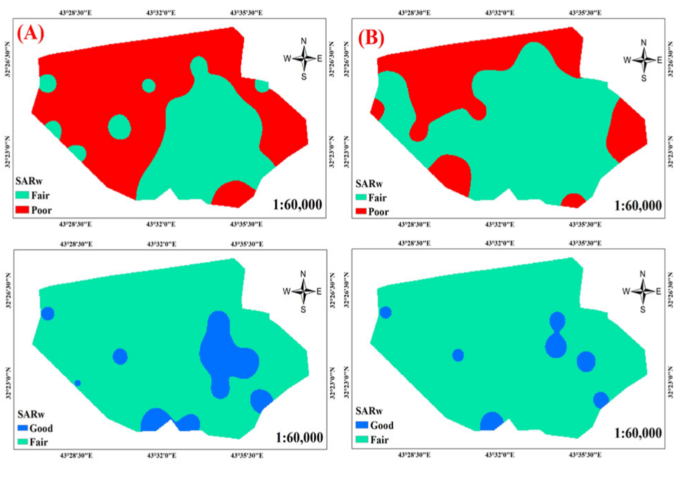

Figure 10: *A, Sodium adsorption rate in groundwater in December 2023; B, Sodium adsorption rate in groundwater in January 2024; C, Sodium adsorption rate in groundwater in February 2024; D, Sodium adsorption rate in groundwater in March 2024.*

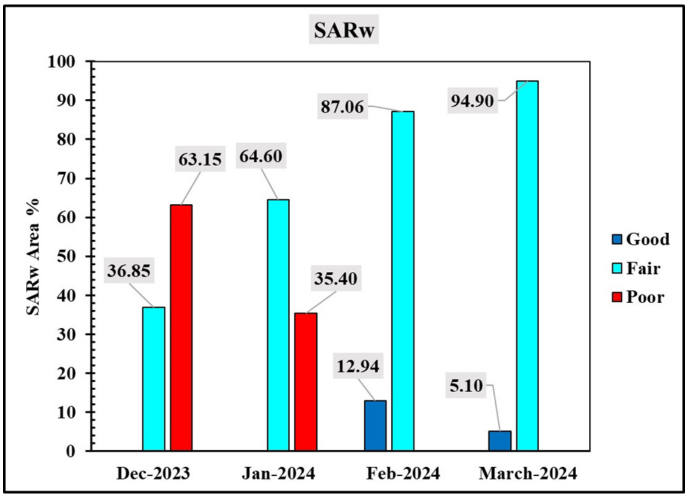

Figure 11: *Percentages of areas of sodium adsorption rate categories in groundwater.*

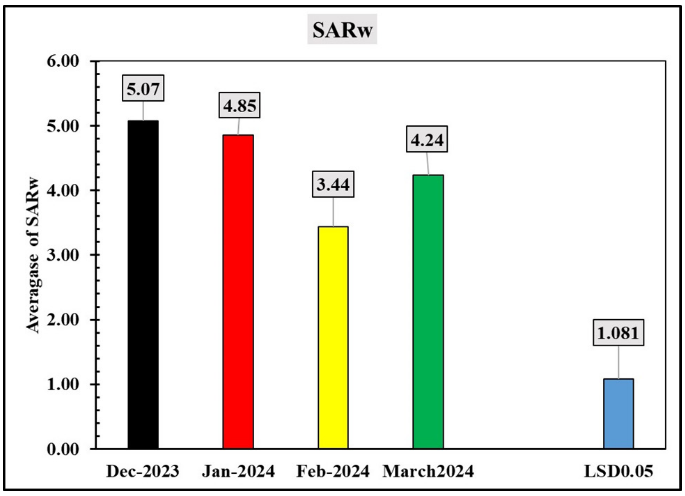

Figure 12: *Significant variation between sodium adsorption rates in groundwater in ROI.*

Table 4 shows that there is a variation between the rate of sodium adsorption in groundwater during the months of the study. Figure 12 shows the presence of highly significant differences between the months of the study in which the rate of sodium adsorption increased and its decline in the month of February 2024. This may be attributed to a decrease in concentrations of sodium. Sodium due to the availability of rainwater in February under the conditions of the study area, which is consistent with Rajmohan *et al*. (2021), as they showed that an increase in salt concentrations is evident in dry seasons, where evaporation rates are twice the rates of rainfall, but this mechanism changes, so the concentrations of solutes and Including sodium during the groundwater recharge season, which is equivalent to the rainy season in dry areas.

Figure 13 shows that the effects of SARw on the plant health status index (NDVI) produced a coefficient of determination of R^2= 0.87 in February 2024

Table 4: *Descriptive statistics SARw.*

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Dec-2023	30	6.18	2.62	8.	5.069	.4331	2.3721	5.627
Jan-2024	30	5.02	2.86	7.88	4.851	.35554	1.94735	3.792
Feb-2024	30	5.1	1.19	6.29	3.4443	.3503	1.9186	3.681
March-2024	30	5.80	1.08	6.88	4.2363	.39925	2.187	4.782
Valid N (listwise)	30							

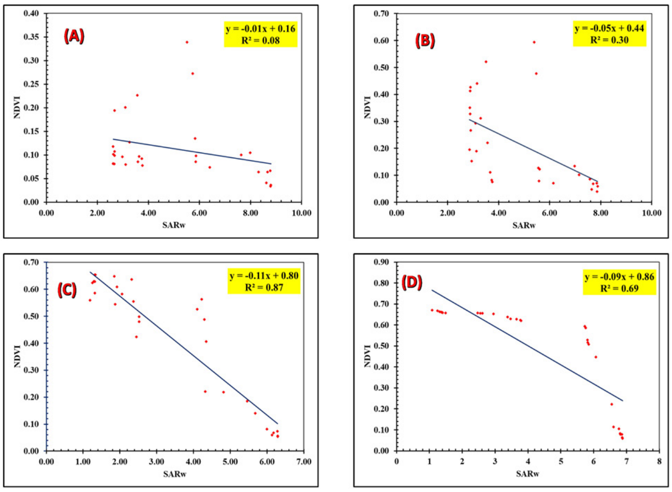

Figure 13: *A, Simple linear regression relationship between SARw and NDVI values in December 2023. B, simple linear regression relationship between SARw and NDVI values in January 2024; C, simple linear regression relationship between SARw and NDVI values in February 2024; D, Simple linear regression relationship between SARw and NDVI values in March 2024.*

and a coefficient of determination of R^2= 0.69 in March 2024, with a negative relationship; confirms the negative impact of the high rate of sodium adsorption. In the health status of wheat in the study area, and from this study it's found that from understanding the relationship between SARw and NDVI, the most critical growth period in which wheat plants are affected by the rate of SARw when irrigated is in February. The fact that the vegetative system is still very young is affected by the osmotic action of sodium, but it may exceed this risk relatively when it intensifies in March, which may explain the lower value of the regression coefficient in this month compared to the February.

Results and Discussion

The results of this study showed that the integration of geospatial analysis of groundwater quality indicators associated with its suitability for irrigation of wheat plants, while monitoring its growth and physiological health using Sentinel-2 data, especially the use of NDVI is of great importance in the sustainable management of water resources and preserving the ecosystem.

The understanding of the hydro chemical relationship of groundwater with the growth of wheat plants contributes to enabling farmers and owners of promising agricultural projects in desert areas, including the Karbala desert, to develop effective strategies to mitigate the negative effects of salinity on plant cover and ensure the health of our agricultural ecosystems in the future.

Conclusions and Recommendations

Fluctuating groundwater quality negatively affects the growth of wheat plants, especially in the early stages. In the late stages of growth, the deterioration of the suitability of groundwater for irrigation is observed, which causes salt stress on the wheat plant, which may hasten the end of its life cycle before the grain is full, which causes poor marketing quality. It is believed that NDVI is useful in diagnosing the health status of the wheat plant and served as an early warning means to avoid any phlegmatic problems associated with irrigation with water of inappropriate quality. The salinity of groundwater has a greater impact on the growth of the wheat plant than SARw, especially as the growth stages progress in the study area, and this is due to the hydrochemical state within the groundwater, where the effect of dissolved sodium ion decreases due to the dissolution of lime and the release of calcium and magnesium in concentrations that reduce the toxicity of sodium to the wheat plant. The use of field methods for monitoring NDVI by a drone is borne out by the importance of this indicator in diagnosing the health status of the wheat plant in the conditions of Western Karbala. To avoid watering before testing and treating groundwater to reach the variety, that achieves the highest economic output and ensures the sustainability of the soil resource from degradation due to salt accumulation. Evaluation of water drainage systems in the study area and taking advantage of their circulation in the operation of agricultural systems in the conditions of Western Karbala desert.

Novelty Statement

This study monitored sustainability of groundwater resources in agricultural systems in the desert environment of West Karbala, Iraq for wheat growers.

Author's Contribution

Halla H. Ahmed: Methodology and results.
Aurass Muhi Taha Al Waeli: Geospatial analysis.
Fadia W. Al-Azawi: Write-up and proofreading.

Conflict of interest
The authors have declared no conflict of interest.

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