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Geospatial Assessment of the Effect of Groundwater Salinity on NDVI in Western Karbala

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Abstract - Groundwater is a vital resource for many targets, including drinking, irrigation, industry, and many other purposes. However, increasing salinity threatens this precious resource, which negatively affects its quantity and quality. This issue is especially manifested in arid and semi-arid regions, where the demand for water is increasing. The importance of this research lies in understanding the mechanisms of salinity's impact on groundwater especially in diverse hydrological and geological contexts. This study is also looking for monitoring and surveillance the impact of changes in groundwater quality indicators in western Karbala on wheat growth using Sentinel-2 satellite imagery. The study also evaluated the variations in the quality of groundwater particularly salinity-related indicators, where it was expressed in terms of the values of Normalized Difference Vegetation Index (NDVI). Water samples collected in sterile, sealable plastic containers, each with a capacity of 250 ml. Water was collected several times at intervals consistent with the time of the satellite image to accurately measure the impact of groundwater quality and characteristics on plant health. Filter paper was used to remove suspended particles and impurities.The fieldwork period was distributed over several months (December, January, February, and March). This study found that there are three Total Dissolved Solids (TDS) varieties during the period of study. Therefore, the impact of the salinity of irrigation water groundwater salinity (ECw) and TDS values can be inferred from its negative impact on plant growth depending on the NDVI values, which can be monitored periodically by obtaining satellite images, That is an early warning means for any phycological damage to the plant due to the deterioration of water quality indicators and suitability for irrigation, one of the most important indicators of which is the salinity status. This approach allows a deeper understanding of the correlation between subsurface water salinity and vegetation health, which helps in making informed decisions for the management of Water Resources and agricultural land.

التقييم الجغرافي لتأثير ملوحة المياه الجوفية على مؤشر الغطاء النباتي الطبيعي في غرب كربلاء

هالة حقي احمد، اوراس محي طه ، فاديه وضاح العزاوي
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المستخلص - تعتبر المياه الجوفية موردا حيويا للعديد من الاستخدامات، بما في ذلك الشرب والري والصناعة والعديد من الأغراض الأخرى. ومع ذلك، فإن زيادة الملوحة تهدد هذا المورد الثمين، مما يؤثر سلبا على كميته ونوعيته. تتجلى هذه المشكلة بشكل خاص في المناطق القاحلة وشبه القاحلة، حيث يتزايد الطلب على المياه. تكمن أهمية هذه الدراسة في فهم آليات تأثير الملوحة على المياه الجوفية خاصة في السياقات الهيدرولوجية والجيولوجية المتنوعة. تبحث هذه الدراسة أيضا عن رصد تأثير التغيرات في مؤشرات جودة المياه الجوفية في غرب كربلاء على نمو القمح باستخدام صور الأقمار الصناعية. كما قيمت الدراسة الاختلافات في جودة المياه الجوفية وخاصة

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المؤشرات المتعلقة بالملوحة التي تؤثر على نمو القمح في منطقة الدراسة، حيث تم التعبير عنها من حيث قيم مؤشر الفرق الطبيعي للغطاء النباتي. تم جمع عينات المياه في عبوات بلاستيكية معقمة وقابلة للغلق، سعة كل منها ٢٥٠ ملي لتر. تم جمع المياه عدة مرات على فترات تتفق مع وقت صورة القمر الصناعي لقياس تأثير جودة المياه الجوفية وخصائصها على صحة النبات بدقة. تم استخدام ورق الترشيح لإزالة الجسيمات العالقة والشوائب. فترة العمل الميداني توزعت على عدة أشهر (كانون الأول، كانون الثاني، شباط، آذار). وجدت هذه الدراسة أن هناك ثلاثة أنواع من المواد الصلبة الذائبة الكلية. لذلك، يمكن الاستدلال على أثر ملوحة المياه الجوفية وقيم المواد الصلبة الذائبة على تأثيرها السلبي على نمو النبات اعتمادا على قيم مؤشر ملوحة المياه الجوفية، والتي يمكن رصدها بشكل دوري عن طريق الحصول على صور الأقمار الصناعية، والتي تعد وسيلة إنذار مبكر لأي ضرر نباتي يلحق بالمصنع بسبب تدهور مؤشرات جودة المياه ومدى ملاءمتها للري. يتيح هذا النهج فهما أعمق للعلاقة بين ملوحة المياه الجوفية وصحة الغطاء النباتي، مما يساعد في اتخاذ قرارات مستنيرة لإدارة الموارد المائية والأراضي الزراعية.

الكلمات المفتاحية: المياه الجوفية، مؤشر الغطاء النباتي المتباين الطبيعي، ترجيح المسافة العكسية، ملوحة المياه الجوفية، إجمالي المواد الصلبة الذائبة.

Introduction

Remote sensing and GIS are vital for evaluating, monitoring/Surveillance, and preserving groundwater resources, especially in changing climates. Finding areas where groundwater recharge is most likely is crucial for protecting and managing its quality. In arid regions, groundwater is extracted extensively due to its importance for various uses Albhadili *et al.*, 2025. The rivers may be subjected to environmental degradation due to many human effects Al-Zubaidi, 2025.

One of the essential components of life is water Al-Fartusi, 2025. One of the most important indicators of groundwater suitability for plant irrigation is the values of electrical conductivity of dissolved salt concentrations in groundwater ECw and TDS. This is attributable to their direct impact on the plant's physiological state.

NDVI derived from satellite images, serves as a reliable indicator of vegetation cover and its strength, allowing monitoring and evaluation of large-scale vegetation dynamics over time. The Geospatial assessment of the groundwater quality in western Karbala was discussed by Al Waeli *et al.*, 2021, but it did not address the impact of these indicators on the status of health for the dominant economic plant cultivated in ROI.

Wheat constitutes one of the most vital cereal crops worldwide and that the production of wheat in sufficient quantities contributes to providing main food for the population and meeting their nutritional needs because of its important turns in the national/domestic economy and in promoting international exchange. The development of the ability to produce wheat at a high level also contributes to the achievement of the state's self-reliance in food supply. Instead of relying on wheat imports from abroad out, the state can rely on its domestic production to meet the requirements of its population and preserve independence in the food section Al Waeli *et al.*, 2020.

Due to the lack of watering, most projects for wheat cultivation have tended to rely on groundwater as the main source of irrigation, which requires proper attention to this important national resource in terms of analysis and study to ensure its sustainability, so it became necessary to pay attention to the assessment of groundwater salinity indicators to make decisions that serve sustainable agriculture in the country Khudair *et al.*, 2022.

The study of salinity indicators in groundwater that assess its suitability for irrigation is a matter that requires monitoring the impact of these waters on the health status of the plant, so it became necessary to use remote sensing data, especially the spectral guide NDVI to achieve this goal because of its features reflect the physiological state of the plant by increasing its positive values indicates a positive health status of the plant Al Waeli *et al.*, 2024. This study comes to evaluate geospatial analysis of groundwater salinity indicators in Karbala governorate in the western of Iraq and their integration with the values of NDVI derived from Sentinel-2 data to diagnose their hydrochemical impact on the wheat plant health status, which is grown in the desert environment in the west of Karbala/ Iraq, depending on groundwater.

Study Area:

The study region achieved in the west of Karbala, Lat. (32^0 20' 54.1500" N to 32° 27' 37.4362" N) and long. (43°26' 36.8826" E to 43°38' 04.3786" E) on an area of 15414.363441 hectare. Thirty aquifer samples collected and their coordinates landed depend on Global Navigation Satellite System GNSS as shown in Figure 1.

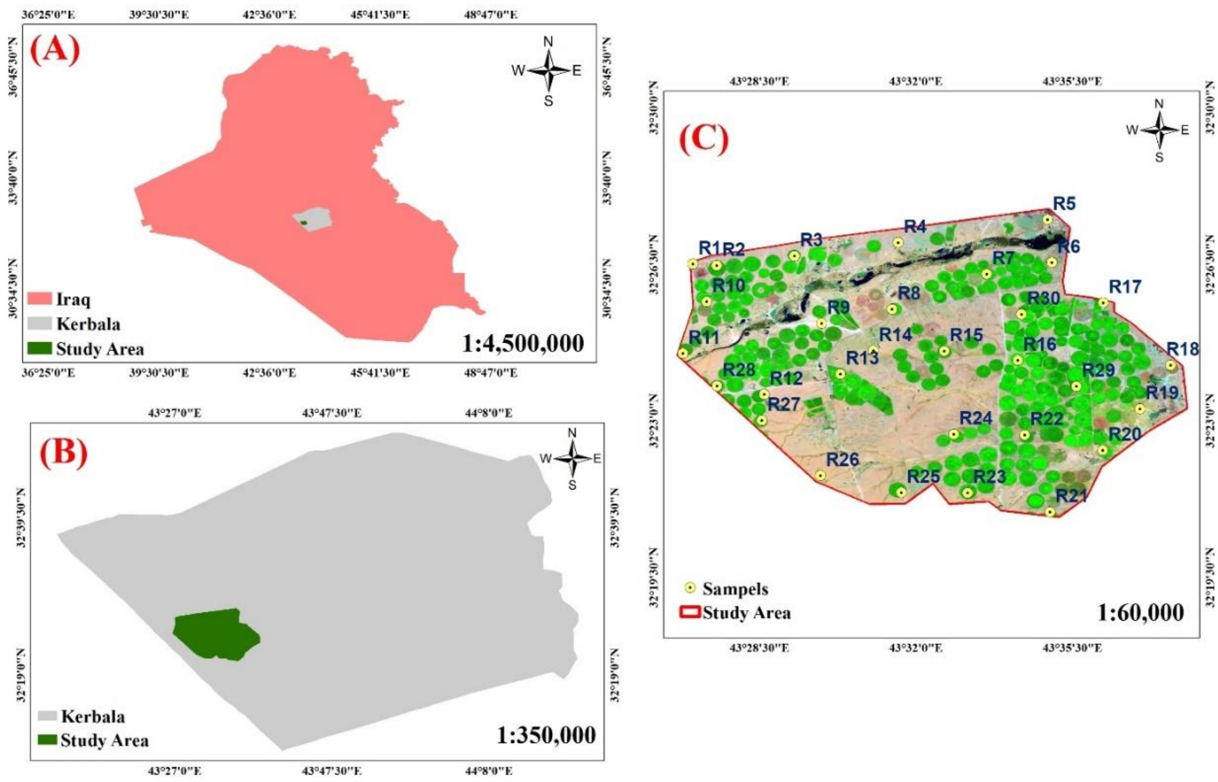

Figure 1. A- Region of Interest; B- study area in Karbala Governorate; C- Distribution pattern groundwater and soil samples

Data and methods

Digital processing for Sentinel-2 data is download from https://dataspace. copernicus.eu/site. Four images are download from this site in the dates 7/12/2023, 16/1/2024, 5/2/2024 and 6/3/2024 respectively.

Radiometric calibration and removal of atmospheric impacts were performed with the ENVI 5.6 program with the FLAASH model - Fast Line of sight Atmospheric Analysis of Spectral Hypercube model according to Wu et al.,2013 and NDVI derived by Rouse *et al.*, 1973 was calculated as in Equation 1:

$$NDVI = \frac{[NIR - Red]}{[NIR + Red]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.[1]$$

Where: NIR: Near Infrared

Laboratory tests:

Laboratory analysis of groundwater properties:

Groundwater samples were filtered, TDS, and ECw is measured with an EC-Meter and the pH of groundwater which are measured with a pH-Meter according to Estefan *et al.*, 2013. Water samples were collected in sterile, sealable plastic containers, each with a capacity of 250 ml. Water was collected several times at intervals consistent with the time of the satellite image to accurately measure the impact of groundwater quality and characteristics on plant health. Filter paper was used to remove suspended particles and impurities.

The fieldwork period was distributed over several months (December, January, February, and March).

Geostatistical Analyst:

Perform Geostatistics Analysis with ArcGIS.Pro. v3.0.1 using Inverse Distance weighing (IDW) under ESRI 2021 and as in Equation 2:

$$Z(x) = \frac{\sum(W_i * Z_i)}{\sum(W_i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..[2]$$

$Z(x)$ is the estimated value at the unsampled location x, W_i is the weight assigned to the ith sample point based on its distance to x, Z_i is the value at the ith sample point.

Statistical analysis:

In order to test the variability for four periods of study/December 2023, January 2024, February 2024, March 2024 between the study attributes, the fewer significant variance test was carried out according to Al Waeli 2020.

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Table 1. Classification of groundwater salinity by Moss and Kress (2016)

TDS (mg. L^{-1})	Classification	Administration
< 320	Excellent	None
320 – 960	Good	Little concern
960 – 1920	Fair	Leach salts from soil as needed
1920 – 3200	Poor	Routinely leach; monitor soils
3200 – 3840	Very Poor	Requires special interest; consult water specialist
> 3840	Unacceptable	Do not use
ECw Micromhos	Classification	Administration
< 500	Excellent	None
500 – 1500	Good	Little concern
1500 – 3000	Fair	Leach salts from soil as needed
3000 – 5000	Poor	Routinely leach; monitor soils
5000 – 6000	Very Poor	Requires special interest; confer water majoring
> 6000	Unacceptable	Do not use

Genstat12 and SPSS programs used to measure the descriptive statistics of the attributes furthermore study the relationships of simple linear regression between groundwater quality indicators and NDVI values. Types of (groundwater and soil) salinity (TDS) according to Moss and Kress, 2016 as the following:

Results and Discussion:

Salinity of groundwater ECw

The results in Figure 2 indicated the existence of three salinity classes of groundwater prevailing in the study area, namely Good, Fair, and Poor, but the very Poor class appeared in December 2023 alone.

Figure 3 shows the percentage distribution of the areas of groundwater salinity varieties in the study area, which are 1.45%, 56.94%, 39.75% and 1.86% for Good, Fair, Poor and Very Poor varieties, respectively, during December 2023, to become 2.16%, 60.80% and 37.04% for Good, Fair and Poor varieties, respectively, during January 2024, and then 32.56%, 44.01% and 23.43% for the good, fair and poor varieties respectively during February 2024 and to return to the same hierarchy as in January to be 3.33%, 69.48% and 27.19% for the good, fair and poor varieties respectively during March 2024 .

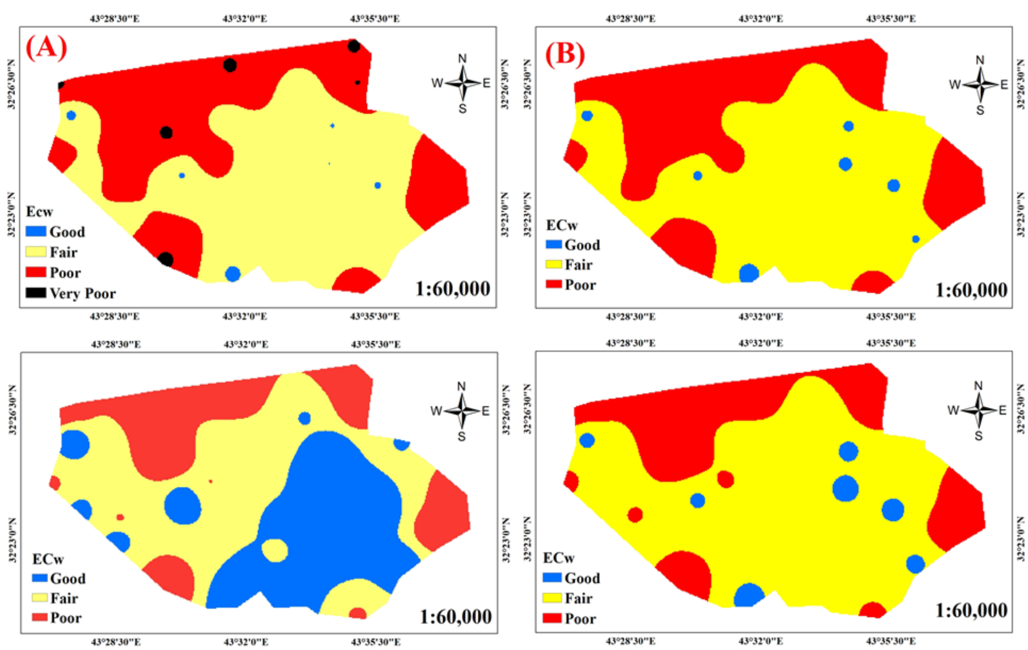

Figure 2. A. Salinity of groundwater in December 2023; B. Salinity of groundwater in January 2024, C. Salinity of groundwater in February 2024, D. Salinity of groundwater in March 2024.

Table 2 shows the existence of a discrepancy in the salinity values of groundwater and reinforces the results of descriptive statistics Figure 4, which show the superiority of salt concentrations in the months of (December 2023 and January 2024) significantly over the month of February 2024, in which the lowest rates of salinity of groundwater reached 1896 Micromhos, which is classified as Fair, which makes it moderately suitable for irrigation.

This variation may be due to changes in groundwater levels, as this leads to fluctuations in the concentrations of salts in groundwater. When the groundwater level decreases, a greater concentration of dissolved salts may occur in groundwater due to the increased concentration. Different waters with different concentrations of salts may merge into the underground system, and the flow and exchange between them may change during the months of the year.

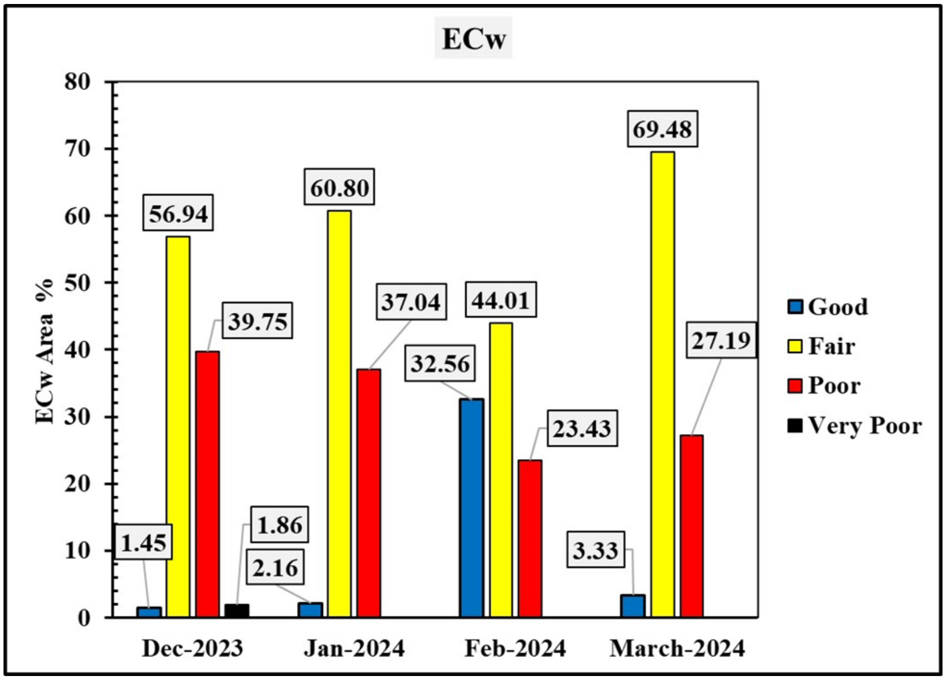

Figure 3. Percentages of areas of salinity varieties of groundwater

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Salt concentrations may be fluctuated in groundwater, so they are affected by more or less saline water, in addition to the influence of seasonal changes in climate, such as rainfall and temperature, on the fluctuation of salt concentrations in groundwater.

Some salts depend on crystallization, evaporation and filtration processes that are affected by climate changes. Rainfall during January and February may allow enhancing the water content, which allows to reduce the concentration of salts. December marks the end of the drought phase and the beginning of winter. The increases are due to the effects of the dry season and elevated evaporation rates that extend for more than nine months in ROI of desert nature.

Awadh *et al.*, 2023 also points out in their study the role of the impact of human activity in increasing salt concentrations in groundwater, as drainage for sewage and chemical cultivation leads to a significant increase in groundwater salinity concentrations, So salinity in groundwater increases during periods of sharp human activity, while Rajmohan *et al.*, 2021 confirm that the effects of dehydrated climate effectively reach aquifer, causing delayed watering and high evaporation rates the salinity of groundwater, however, may drop when high amounts of water are available, particularly in the rainy season, which gives the character saline oscillation, especially for groundwater in desert regions.

Table 2. Descriptive statistics of groundwater salinity (ECw)

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
						Std. Error		
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							

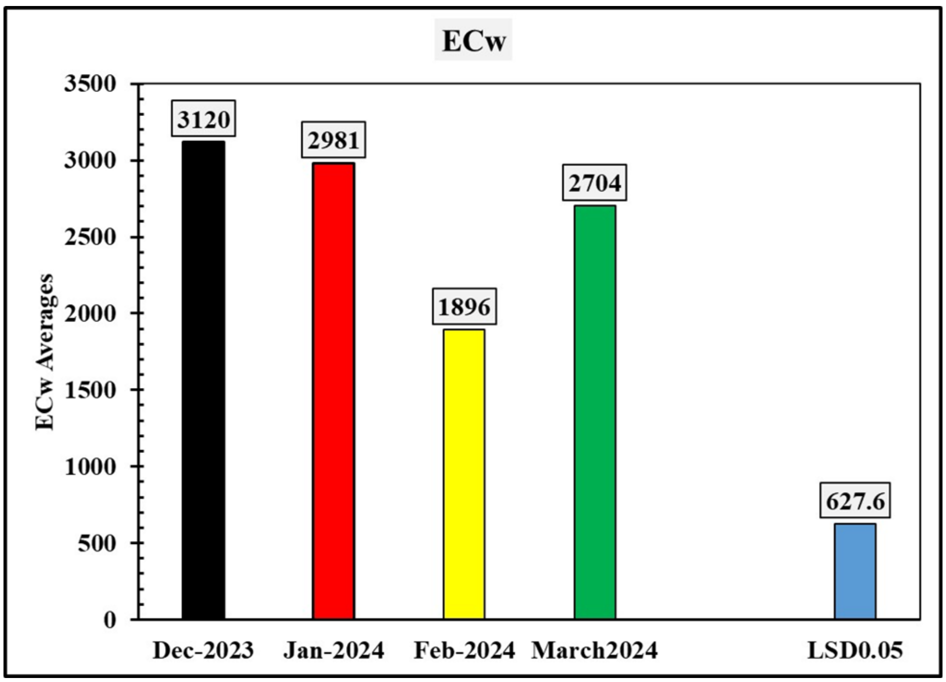

Figure 4. Significance variation between the salinity rates of groundwater in the study area

Total Dissolved Solids (TDS):

Figure 5 shows a noticeable fluctuation between TDS varieties during the study months, with the disappearance of the two very Poor and Unacceptable varieties observed during the months of January 2024 and February 2024 and the presence during the depletion period at the end of the drought December 2023, which we attribute to natural conditions due to climate changes and the length of the dry season in which there is no rain.

The appearance of these two varieties in March 2024 in addition to the above is mainly due to the high consumption of groundwater during this month of the year.

Figure 5-A shows that the distribution of the percentages of areas are 0.06%, 12.15%, 58.08%, 10.77% and 18.94% for good and Fair, Poor, Very Poor and Unacceptable, respectively, during December 2023, from Figure 5-B we can observe the percentage distribution of areas is 0.88%, 62.61% and 36.51% for Good, Fair and Poor items during January 2024, and from Figure 5-C we can observe the percentage distribution of areas is 3.98%, 67.87% and 28.15% for the good, fair and Poor varieties during February 2024, From Figure 5-D, we can observe the distribution of the percentages of areas are 0.32%, 23.91%, 55.24%, 16.22% and 4.31% for the good, fair, poor, very poor and unacceptable varieties, respectively, during March 2024.

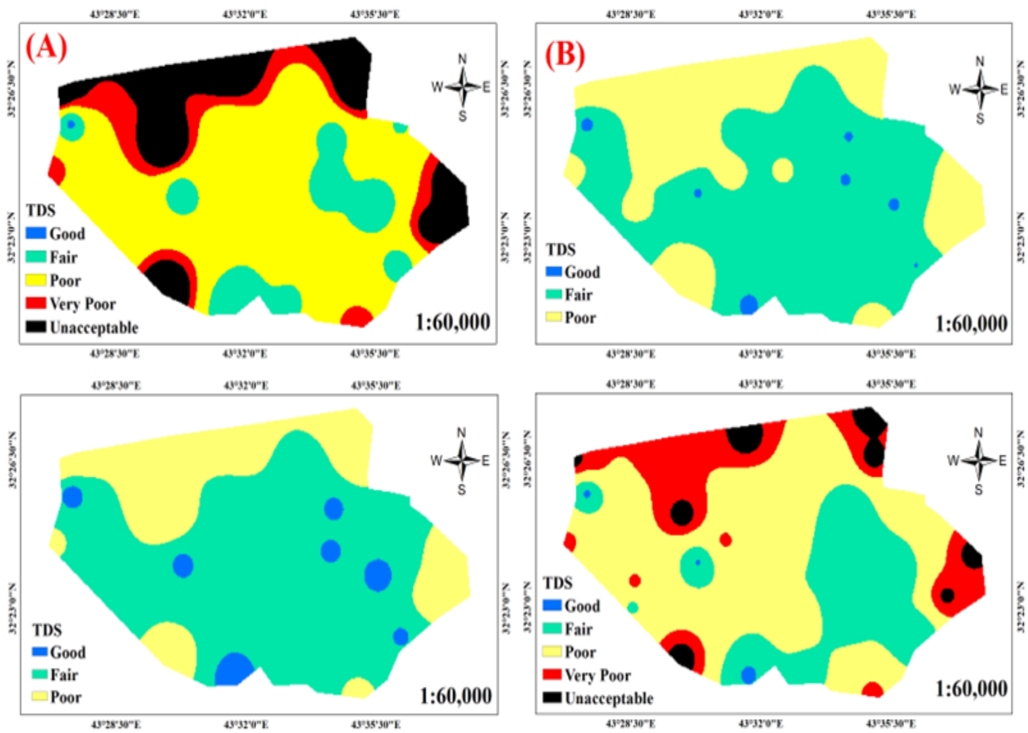

Figure 5. A. TDS in groundwater in the month of December 2023. B. TDS in groundwater in the month of January 2024 C. TDS in groundwater in the month of February 2024. D. TDS in groundwater in March 2024

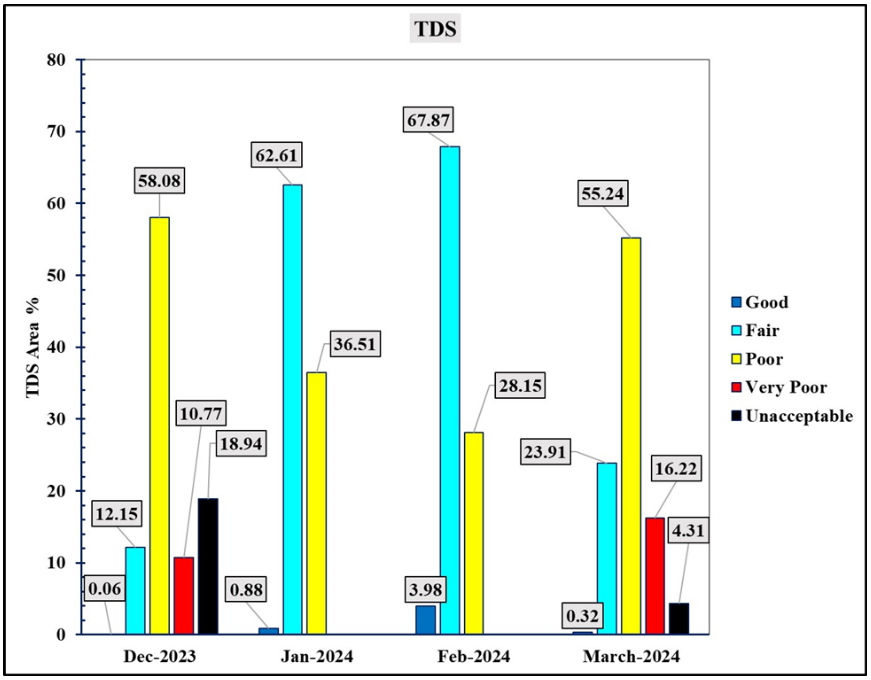

Figure 6. Percentages of areas of groundwater TDS varieties

Table 3 shows the existence of a discrepancy in the values of TDS groundwater and reinforces the results of descriptive statistics. Figure 7, which shows the superiority of the values of TDS groundwater in the months of December 2023 and March 2024 significantly over the months of January 2024 and February 2024, in which they achieved the lowest rates of values of TDS, and it reached 1763 ppm for the month of February 2024 and 1892 ppm for the month of January 2024, which fall within the fair category. This makes it moderately suitable for irrigation during these two months in general.

Table 3. Descriptive Statistics of Total Dissolved Solids (TDS) in Groundwater

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Dec-2023	30	5178	821	5999	3016.23	308.218	1688.180	2849950.875
Jan-2024	30	2270	808	3078	1892.13	149.412	818.365	669721.982
Feb-2024	30	2685	525	3210	1763.20	161.526	884.712	782715.752
March-2024	30	3363	871	4234	2632.07	226.439	1240.259	1538242.685
Valid N (listwise)	30							

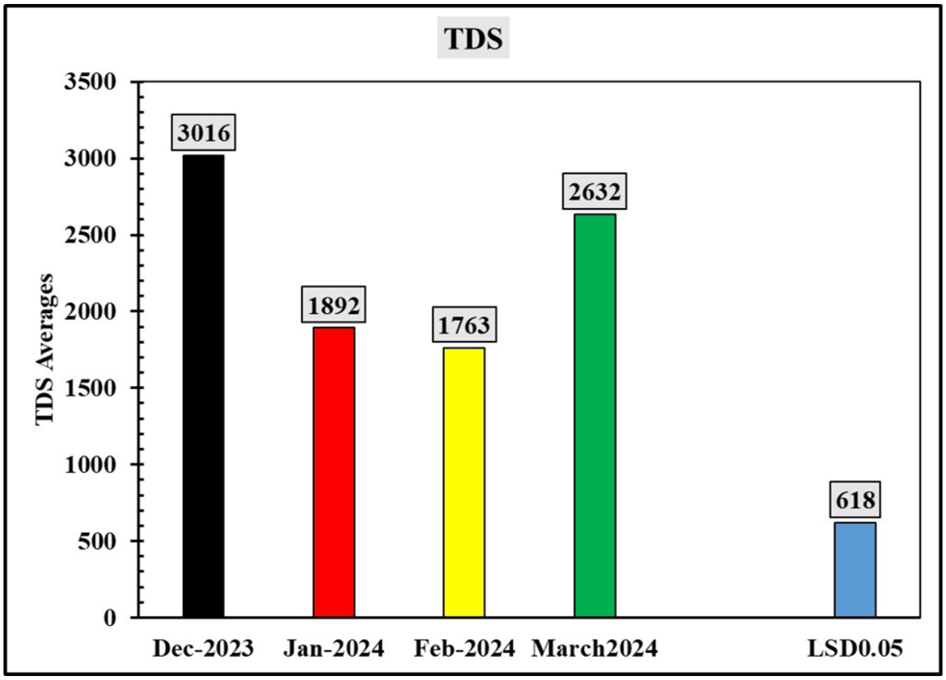

Figure 7. Shows the significant variance between groundwater TDS

This discrepancy may be due to the overlap of natural conditions represented by drought and lack of watering with excessive use of groundwater without taking into account the impact of this consumption on the deterioration of the suitability of irrigation water, as Ubah *et al.,* 2021 indicates that human action has an important role in raising TDS values, especially industrial effluents discharged from these industries on chemical and physical properties and heavy metals, so TDS, which include inorganic compounds increase in the water, the water quality deteriorates, irrigation is not suitable, and it has a harmful effect on the environment. a high TDS index is not evidence of the low suitability of water for irrigation is evidence of an imbalance in that ecosystem.

Ashie *et al.,* 2024 emphasizes the importance of testing TDS in water before using it for irrigation purposes, as it is an important indicator indicating its high values as an indicator of poor water quality and unfit for irrigation and that it is a carrier of pollutants, especially if its feed sources pass near factories and facilities with waste and polluting that cause damage to the plant, This damage may exceed the plant to have a bad impact on human and animal health, measuring TDS is important and necessary to assess the irrigation suitability of water and realistically expresses for various human uses, especially in the field of irrigation.

Normalized Difference Vegetation Index (NDVI)

Figure 8 shows a clear difference in the growth status of the wheat plant, where it was at its lowest in December 2023, as shown in Figure 8-A. It was at its highest flowering in March 2024 as in Figure 8-D. This may be due to the irregularity in the date of planting wheat in the study area, as it extends from the beginning of December to the middle of January 2024, and most of the plant density appears in the eastern and northern part of the study area, while the center of the study area is still in the process of preparing to drill additional wells for the purpose of cultivating this abandoned area, as with the aim of treating it.

Table 4 shows that there is a discrepancy between the upper and lower values between NDVI, which is shown by Figure 9 that there are significant differences in the NDVI values with the continuation of the wheat growing season in the study area, reaching the highest significant increase in March 2024 and February 2024, respectively, on January 2024 and December 2023. This is consistent with the opinion of Mohammed et al., 2018, which indicates the need to assess the state of change in vegetation cover during its growing season using the NDVI manual for clarifying the state of land use and planning wisely to invest agricultural areas to avoid environmental crises.

Al-Helaly *et al.,* 2022 founds that the use of NDVI derived from Sentinel-2 data provides an accurate estimate of the state of land use for agricultural purposes and in order to achieve sustainable management in it. The high TDS index is not evidence of a decrease in the suitability of water for irrigation, but rather evidence that there is an imbalance in that ecosystem.

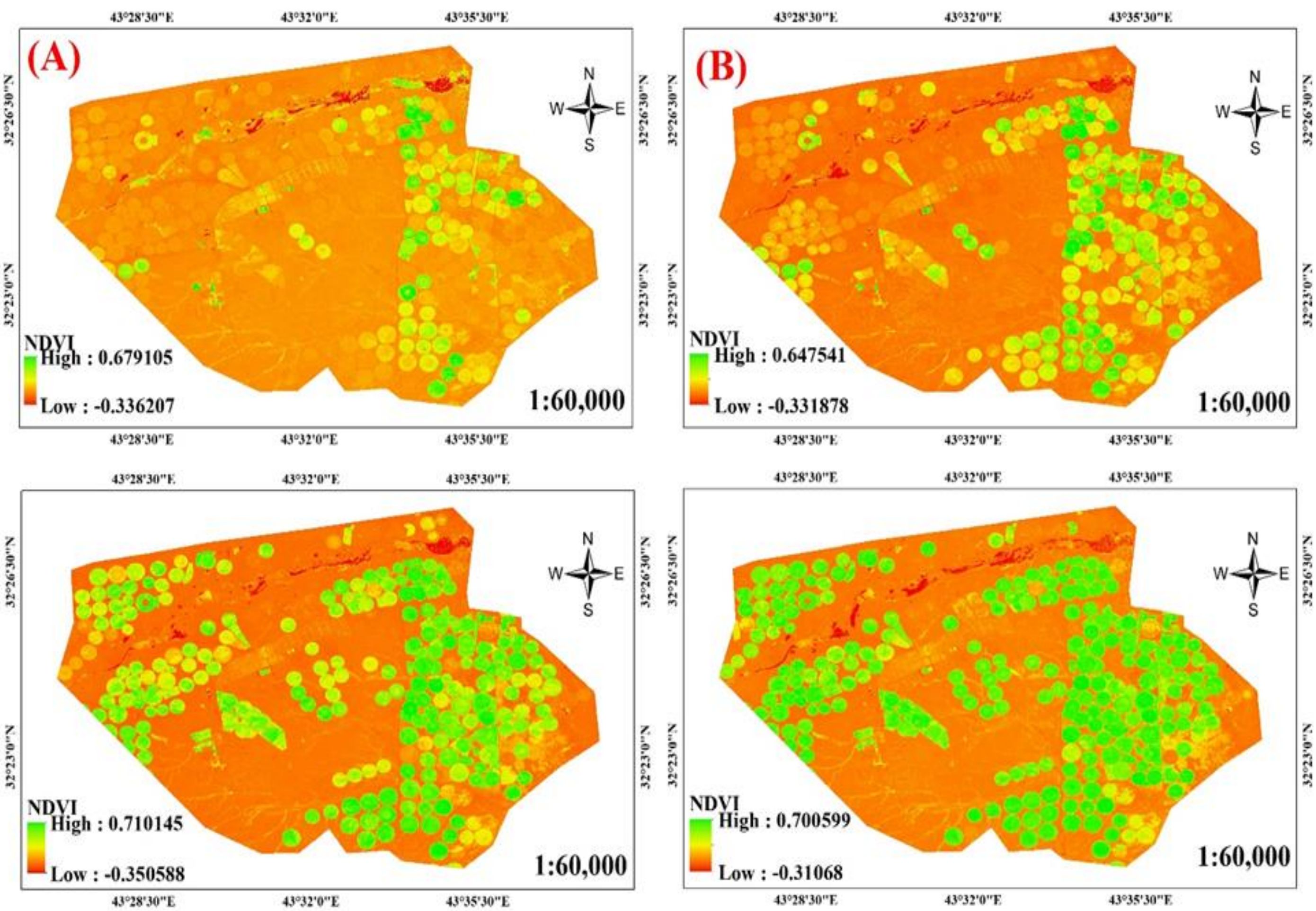

Figure 8. A. NDVI Rate in December 2023. B. NDVI was evaluated in January 2024 C. NDVI Rate in February 2024. D. NDVI values in March 2024

Table 4. The descriptive Statistics of NDVI

Descriptive Statistics of NDVI							
	N	Range	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Dec-2023	30	.305	.034	.338644	.112625	.0126	.068888
Jan-2024	30	.554	.0404	.59415	.21541	.0296	.1618
Feb-2024	30	.5995	.054	.65395	.41514	.0414	.227
March-2024	30	.611	.06004	.67101	.4796	.043761	.2397
Valid N (listwise)	30						

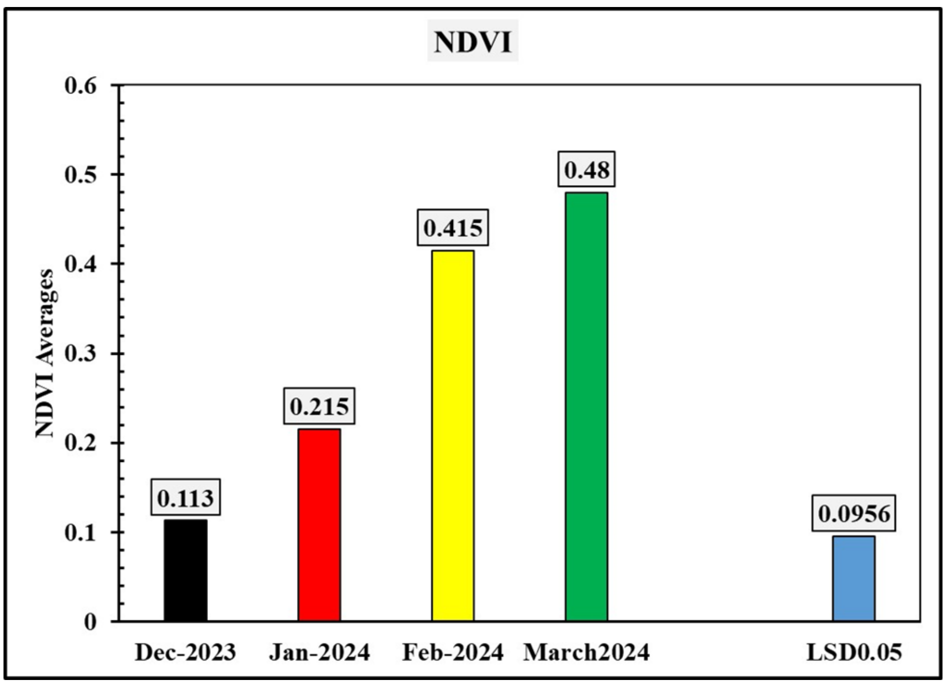

Figure 9. The significance of the variation between the NDVI rates in the study area

Influence of groundwater salinity indicators on NDVI values

Figure 10 shows that the effects of groundwater salinity in the NDVI vegetation Health Status Index productive a determination coefficient of R^2=0.86 in February 2024 and a determination coefficient of R^2=0.85 in March 2024 with a negative relationship. This confirms the negative trace of high salt concentrations on the health status of the wheat plant in the study area.

Understanding the correlation between the salinity of groundwater and the vegetation cover index of vegetation cover (NDVI). It can provide amount information on the trace of salinity on vegetation dynamics and guide sustainable water administration practices. That high levels of salinity adversely affect the strength of vegetation.

The study emphasizes the importance of monitoring and managing groundwater salinity to maintain sustainable agriculture and healthy ecosystems. Al Waeli *et al.*, 2024 believe that the reason for the deterioration of vegetation cover in Iraqi Karbala throughout the last decades is the deterioration in NDVI values due to the adoption of mistaken policies using unknown quality sources for irrigation or irrigation without providing an effective drainage system, This allows the accumulation of salts carried with groundwater in the soil surface over time, which causes a weakening in the health status of plants and a clear shrinkage of agricultural areas in the last ten years.

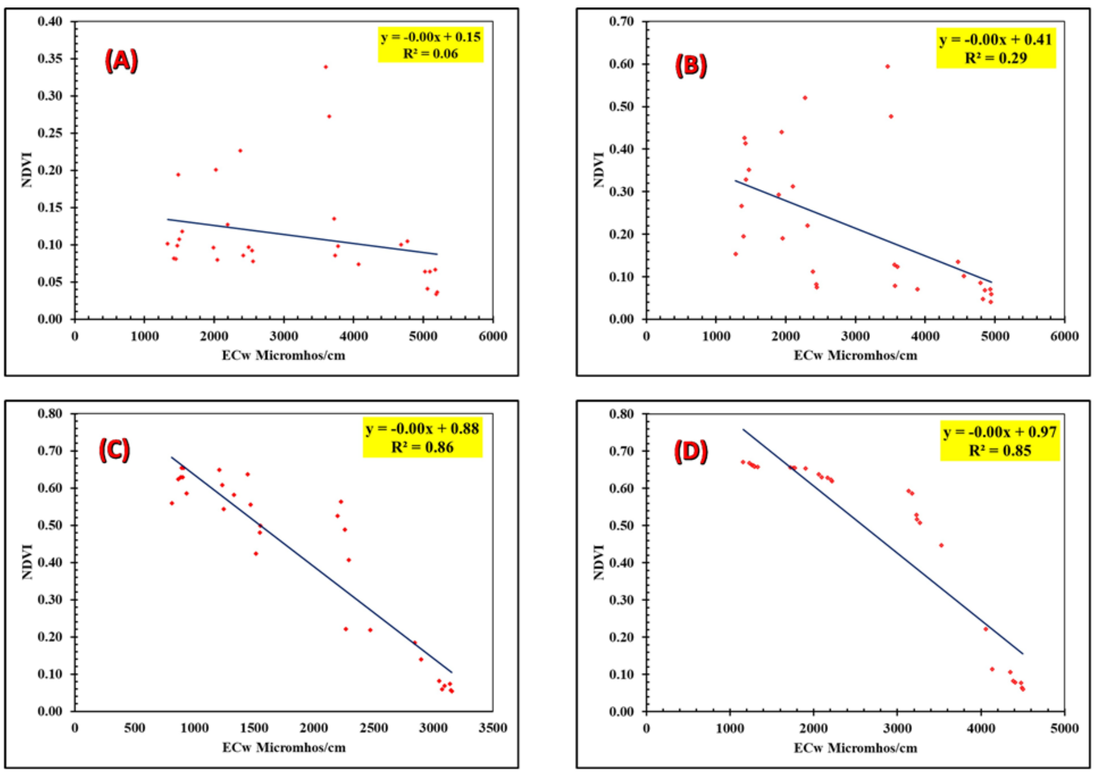

Figure 10. A. The relationship of simple linear regression between groundwater salinity and NDVI values in December 2023; B. The relationship of simple linear regression between groundwater salinity and NDVI values in January 2024, C. The relationship of simple linear regression between groundwater salinity and NDVI values in February 2024, D. The relationship of simple linear regression between groundwater salinity and NDVI values in March 2024.

Figure 10 shows the absence of a significant regression relation between TDS and NDVI in December 2023, where it reached R^2=0.19. This is due to the weak vegetation cover in this month and the fluctuation of planting days between study sites, while the relationship began more clearly in January 2024, as it reached the value of R^2-0.3. Perhaps the decrease in the impact to the novelty of plant growth and the presence of the morale of the TDS values in February and March 2024, where the R^2 values reached 0.90 and 0.72, respectively. Despite the easing of the

TDS values in February 2024, but this did not prevent the impact of this indicator It is important in the plant tissue, which is juicy and juicy causes damage when spraying on the vegetative mass of the plant in this month.

We believe that the fluctuation of the effect of TDS on the health status of the vegetation is related to the type of solutes as well as their quantity, and that the position of groundwater as an open system. This allows the leakage of solutes from industrial wastewater to it clearly affects the disruption in the environmental balance by adding pollutants in the plant environment, and the type of salt solutes, especially a harmful osmotic effect on the plant tissue. When TDS is high, it becomes difficult for the plant to absorb water, which leads to wilting and shrinkage of plant cells, and consistent with Ogugua *et al.*, 2023 that high TDS values in groundwater affect the pH and change it, which may make pollutants It may be represented by plants in their tissue and cause harm to humans when eating fruiting parts containing these pollutants, although their physiological effects on the plant may be obvious.

Therefore, we believe that in our study it is possible to understand the state of pollutants in groundwater in terms of their damage to plant growth, which we can monitor periodically depending on the NDVI values. From remote sensing data and NDVI values in March 2024.

Spatial assessment of the impact of groundwater salinity on the health status of plants is aimed at serving the sustainable development of agricultural systems in desert areas, especially promising projects in the west of Karbala, Iraq. It is appropriate to rely on remote sensing data and what digital processing software offers us on it, I mean the modified natural plant index (NDVI), which is one of the most prominent functions of the health status of plants. By analyzing the data and comparing the salinity indicators and NDVI values in different regions, a possible relationship between them can be determined.

The analysis can show if the salinity of groundwater affects plant growth and vegetation coverage in the area and as we found in this study, whenever there are high concentrations of salinity in groundwater, it has a negative impact on plants and therefore can have a negative impact on NDVI values.

Conclusions and Recommendations

There is a strong inverse relationship between vegetation health and groundwater salinity in western Karbala, which means that the higher the groundwater salinity, the lower the vegetation vitality (as shown by the NDVI index). This degradation may lead to land desertification, which poses a significant threat to food security and the local economy of the region. Therefore, we recommend that the analysis be comprehensive and multifactorial to determine the correlation between NDVI and groundwater salinity in West Karbala, especially that the ArcGIS Pro environment accommodates all the factors affecting any environmental and agricultural phenomenon and provides bases for future strategies that contribute to providing decision makers with a reliable and sustainable geospatial database.

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