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Utilization of Geospatial Technologies for the Spatial Distribution of Available Copper in Selected Areas of Basrah Governorate

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Abstract

In order to study the spatial distribution and develop maps for the assessment of available copper in agricultural soils of Basrah Governorate in southern Iraq using geospatial technologies, two regions were selected—one in southern Basrah and the other in the north—covering areas of 4,086.58 hectares and 34,561.50 hectares, respectively. A total of 36 representative soil samples were collected from each region. Satellite imagery from the Landsat 8 sensor for October 2023 was utilized. Laboratory analyses were conducted, and correlation relationships were evaluated between available copper content and various soil properties. The results showed that in the southern Basrah region, the study area was classified into two categories: 69% of the total area exhibited a deficiency in available copper, while 31% had low available copper content. In contrast, the northern Basrah region was classified into four categories: 17.5% of the area had very low available copper content, 32% had low content, 36.5% had medium content, and 14% had high content of available copper. Correlation analysis revealed significant relationships between available copper and both soil pH ($r = 0.351$) and organic matter content ($r = 0.384$) in the soils of northern Basrah. A significant correlation was also observed with electrical conductivity ($r = 0.368$) in the soils of southern Basrah. These findings indicate that most soils in the study areas require copper supplementation through fertilization in order to achieve optimal productivity and ensure food security.

Keywords: Micronutrients, Available Copper, Geospatial Technologies, Spatial Distribution.

I. Introduction

Prasad and Power (1997) indicated that the primary source of micronutrients in the soil is the solid phase of the soil system, which contains quantities that far exceed the actual requirements of cultivated crops. However, the availability of these nutrients in plant-accessible forms is limited. The mineral fraction, made available through processes such as weathering and erosion, and the organic fraction (organic matter) of the solid phase play a significant role in supplying plant-available micronutrients. Tripathi et al. (2015) highlighted the critical importance of micronutrients due to the fundamental dependence of plants on them, given their direct influence on plant physiological activities. Although micronutrients are often abundant in soils, their availability is frequently limited due to various factors. Among the most essential micronutrients for plant growth and development are zinc, iron, manganese, boron, and copper, which are required in small amounts but are indispensable for proper physiological functioning. Zewide and Sherefu (2021) stated that micronutrients are crucial for achieving optimal plant growth, yield quality, and quantity, comparable in importance to macronutrients, despite their lower required concentrations. Plants acquire these nutrients from the soil, provided they are present in sufficient quantities, most commonly through the decomposition of organic matter or the application of chemical fertilizers—either directly to the soil or via foliar spraying. Dewangan et al. (2023) elaborated on the vital roles of micronutrients in plant biochemical processes, such as photosynthesis, respiration, and nitrogen fixation. These nutrients are also involved in the synthesis of essential enzymes and other critical compounds. Barker and Pilbeam (2015) emphasized that plants need micronutrients for the biosynthesis of peptides, proteins, and carbohydrates. Deficiency of micronutrients in soil can result in reduced crop yields, stunted growth, and poor crop quality. Furthermore, micronutrients enhance plant resistance to environmental stresses, reduce the need for chemical

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inputs, and contribute to environmental sustainability. Therefore, the application of micronutrients has a positive impact on both the productivity and quality of agricultural crops. Copper, in particular, is an essential element for plants as it functions as a component of enzymes, regulates enzymatic activity, and accelerates oxidation reactions. It also plays a role in nitrogen metabolism, protein and hormone synthesis, respiration, and photosynthesis. According to Kumar et al. (2021), the typical copper content in plants ranges from 5 to 30 mg kg^{-1}. Gupta et al. (2008) reported that deficiency symptoms of most micronutrients usually appear on the younger, upper leaves of plants, whereas toxicity symptoms tend to manifest on older leaves. In the case of copper, even mild to moderate deficiencies can cause small, delayed wheat heads (by 10–14 days), and symptoms vary among species, including necrosis in young flower tissues, dwarfism, chlorosis or whitening of young mature leaves, dieback in citrus branches, and fruit drop. Copper toxicity, on the other hand, adversely affects physiological and biochemical processes and plant growth, leading to reduced leaf area, impaired photosynthesis and grain production, inhibition of root and shoot elongation, and disruption of the uptake of other essential nutrients. The typical concentration of copper in plant dry matter is around 0.001%. When concentrations exceed 20 ppm, copper becomes toxic to wheat plants (Zhang et al., 2022).

II. Materials and Methods

Study Location

The study was conducted at two sites located in the southern and northern regions of Basrah Governorate, Iraq. The first study area was in the Safwan District, situated in the southern part of Iraq. This area is geographically located between longitudes 47°31′ and 47°53′ E, and latitudes 29°59′ and 30°16′ N. It is bordered to the north by Dhi Qar Governorate, to the south and west by the Arabian Gulf, and to the east by the Zubair District. The total area of the studied site is approximately 4,086.58 hectares. The second study area lies between longitudes 47°14′ and 47°42′ E, and latitudes 30°54′ and 31°11′ N. It is bordered to the north by Maysan Governorate, to the south by the Hartha District, to the west by the Zubair District, and to the east by the Republic of Iran. The total area of this studied region is approximately 34,561.50 hectares, as illustrated in Figure 1.

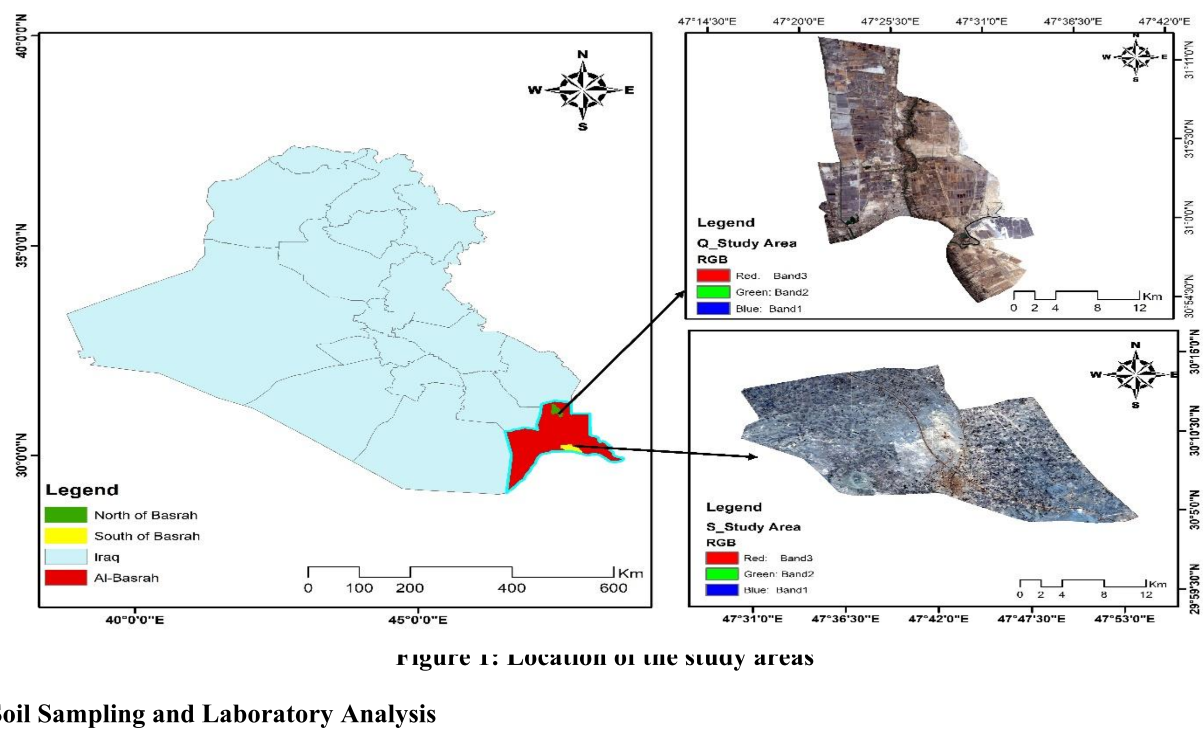

Figure 1: Location of the study areas

Soil Sampling and Laboratory Analysis

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Soil samples were collected from a depth of 0–15 cm, with a total of 36 composite samples obtained randomly from each of the two study sites. All sampling points were located in agricultural lands cultivated with wheat, as illustrated in Figure 2.

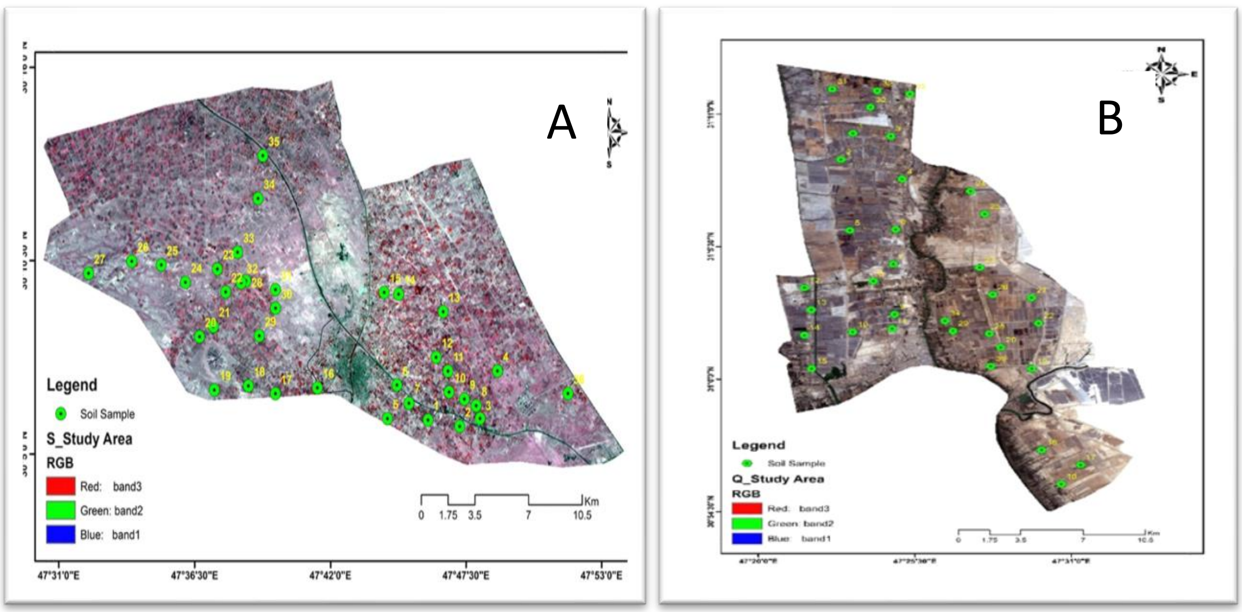

Figure 2: Study points in the north (B) and south (A) of Basra

A 15 g portion of air-dried soil, passed through a 2 mm sieve, was placed into a 100 mL plastic beaker. To this, 30 mL of an extraction solution was added. The extractant was prepared using 1.9676 g of DTPA (Diethylenetriaminepentaacetic acid), 13.3 mL of TEA (Triethanolamine), and 1.47 g of $CaCl_2 \cdot 2H_2O$, with the pH adjusted to 7.3. The available micronutrients were then determined using an Atomic Absorption Spectrophotometer, as presented in Tables 1 and 2. Correlation coefficients were subsequently calculated between the available iron content and selected soil properties, as shown in Tables 3 and 4.

The particle size distribution of the soil fractions was determined using the pipette method. Sand was separated using a 50-micron sieve, while silt and clay fractions were separated based on their settling velocities, as described by Black et al. (1965). Electrical conductivity (EC) was measured in a 1:1 soil-to-water extract using a Lovibond Con 200 conductivity meter at 25°C, following the method described by Page et al. (1982). Soil pH was measured in a 1:1 soil-to-water suspension using a Lovibond pH 200 pH meter, according to the procedure outlined by Page et al. (1982). Total carbonates were determined following the method described by Jackson (1958), in which carbonates were decomposed using 1N HCl. The residual acid was then titrated with 1N NaOH using phenolphthalein as an indicator. Organic carbon content was determined using the Walkley–Black method as described in Page et al. (1982). This involved the oxidation of organic matter with potassium dichromate in the presence of sulfuric acid, followed by titration with ammonium ferrous sulfate. The percentage of organic matter was calculated by multiplying the organic carbon content by the factor 1.724.

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3. Spatial Distribution of Available Copper in Soil

Databases were developed for soil unit maps, sample collection site locations, and spatial distribution maps of soil properties using the Ordinary Kriging interpolation method with the Spherical model, as shown in Figures 4 and 5, in accordance with the methodology described by Burroughs and McDonnell (2000). Spatial classification of chemical properties was also based on the Kriging method used for physical properties, as reported by Abdulmanov et al. (2021). ArcGIS 10.4.1 software was employed to perform data entry, storage, retrieval, and processing as needed. In addition, spatial and descriptive databases were constructed and integrated with other software tools. The results were presented in the form of maps, charts, and tables. The Normalized Difference Vegetation Index (NDVI) was used as an indicator sensitive to the presence and condition of green vegetation. NDVI is a key metric for assessing vegetation status, based on the principle that healthy green plants exhibit high reflectance in the near-infrared wavelength range (0.7–1.3 µm) and strong absorption in the red wavelength range (0.6–0.7 µm), as per the equation provided by Rouse et al. (1974):

$$NDVI = \frac{NIR - Red}{NIR + Red} = \frac{B5 - B4}{B5 + B4}$$

Where:

- B (Band): Refers to the spectral band used in satellite imagery.
- NIR (Near-Infrared): Corresponds to Band 5 of the imagery.
- Red: Refers to the red spectral band, corresponding to Band 4.

III. Results and Discussion

Concentration of Available Copper in Soil

Table 1 presents the values of available copper in the northern region of Basrah. The highest concentration was recorded at Site 30, reaching 4 mg kg⁻¹, while the lowest was observed at Site 21, with a value of 0.56 mg kg⁻¹. The remaining sites showed copper concentrations that ranged between these two extremes. Table 2 shows the values of available copper in the southern region of Basrah. The maximum concentration was recorded at Site 4, reaching 0.32 mg kg⁻¹, whereas the minimum was at Site 24, with a value of 0.02 mg kg⁻¹. The rest of the sites exhibited intermediate values within this range. These variations may be attributed to several factors. One of the main reasons is the increase in soil pH, which reduces the concentration of copper in the soil solution. This occurs due to the replacement of exchangeable copper ions with calcium ions, leading to the transformation of copper from a plant-available form to less available or unavailable forms. Additionally, the nature of the parent material influences the amount of available copper in the soil. Organic matter also plays a significant role in copper availability, depending on the type of complexes formed—whether they are soluble or insoluble.

Table 1: Available Copper in the Northern Basrah Region

Site	Fe (mg kg^{-1})	Site	Fe (mg kg^{-1})	Site	Fe (mg kg^{-1})
1	2.57	13	3.77	25	0.54
2	2.41	14	2.54	26	1.12
3	3.35	15	2.44	27	1.23
4	2.44	16	2.26	28	0.96
5	1.95	17	1.78	29	1.99
6	3.32	18	2.68	30	4.00
7	1.95	19	1.05	31	2.72
8	2.67	20	0.97	32	2.41

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9	1.26	21	0.56	33	2.22
10	1.82	22	1.52	34	1.77
11	1.55	23	2.36	35	2.68
12	1.42	24	3.33	36	3.64

Table 2. Available Copper in the Southern Basra Region

Site	Fe (mg kg⁻¹)	Site	Fe (mg kg⁻¹)	Site	Fe (mg kg⁻¹)
1	0.20	13	0.03	25	0.19
2	0.18	14	0.13	26	0.12
3	0.07	15	0.05	27	0.18
4	0.32	16	0.10	28	0.08
5	0.13	17	0.20	29	0.14
6	0.10	18	0.04	30	0.06
7	0.19	19	0.03	31	0.11
8	0.20	20	0.04	32	0.14
9	0.13	21	0.07	33	0.07
10	0.14	22	0.13	34	0.07
11	0.11	23	0.18	35	0.10
12	0.08	24	0.02	36	0.04

4.2 Relationship Between Available Copper and Soil Properties

The results presented in Tables 3 and 4 indicate the existence of correlations between the concentration of available copper and certain soil properties in both southern and northern regions of Basrah. In the southern region, a statistically significant positive correlation was observed between available copper and electrical conductivity (r = 0.368), while correlations with the other studied soil properties were not statistically significant. In the northern region of Basrah, significant correlations were found between available copper and both soil pH (r = 0.351) and organic matter content (r = 0.384). However, no significant correlations were observed between copper availability and the remaining soil properties. These findings are consistent with the results reported by Naskar and Das (2021), Al-Bayati et al. (2021), Wei et al. (2006), and Dhaliwal et al. (2021).

able 3. Correlation Relationships Between Available Copper and Selected Soil Properties in the Southern Basra Region

Parameter	pH	EC	O.M	$CaCO_3$	Texture
Cu	0.351*	$0.093_{n.s}$	0.384*	$0.141_{n.s}$	$0.124_{n.s}$

Table 4. Correlation Relationships Between Available Copper and Selected Soil Properties in the Northern Basra Region.

Parameter	pH	EC	O.M	$CaCO_3$	Texture
Cu	$0.013_{n.s}$	0.368*	$0.064_{n.s}$	$0.236_{n.s}$	$0.112_{n.s}$

4.3 Spatial Distribution of Available Copper

The results presented in Figures 4 and 5 illustrate the status of available copper in the soils of the study areas. In the southern region of Basrah, approximately 69% of the total study area—equivalent to 30,363.58 hectares—was found

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to be deficient in available copper, while 31% of the area, or 13,717.76 hectares, exhibited low copper content. In the northern region, 17.5% of the area (6,038.51 hectares) suffered from copper deficiency, while 32% (11,271.81 hectares) had low copper content, 36.5% (12,375.35 hectares) had moderate copper content, and 14.0% (4,857.31 hectares) had high copper content. These results indicate that the majority of the soils in the study areas either require or are likely to respond positively to copper fertilization.

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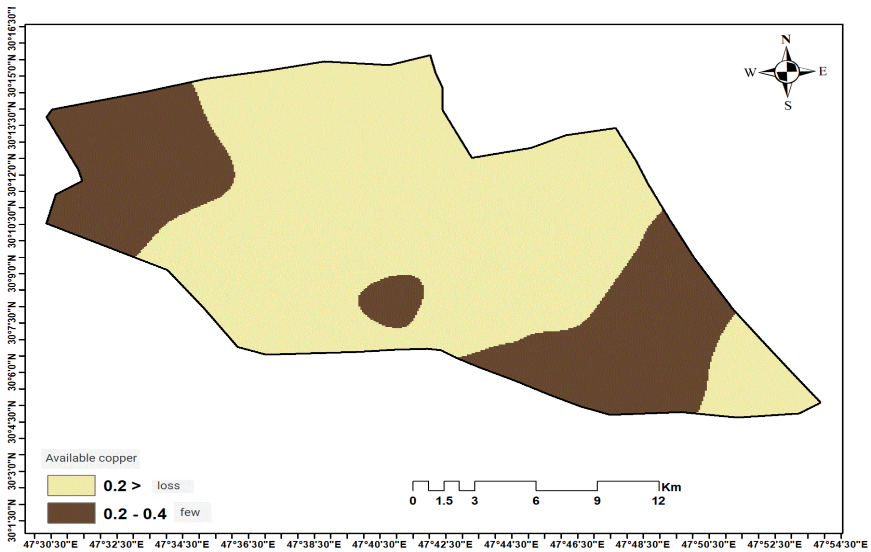

Figure 3. Spatial Distribution of Copper in Southern Basra

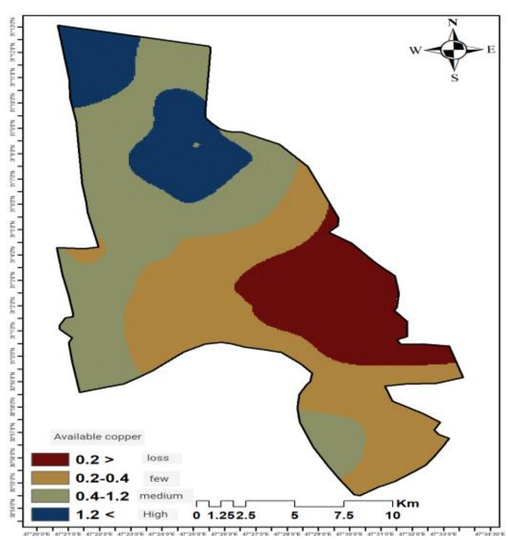

Figure 4. Spatial Distribution of copper in Northern Basra

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Spectral evidence

One of the most significant enhancements applied to satellite imagery is the use of spectral indices, particularly digital indices, which are considered the optimal choice for detecting differences that cannot be observed through the basic color bands of imagery. In this study, ArcGIS 10.4.1 software was used to calculate digital indices.

4.4.1 Normalized Difference Vegetation Index (NDVI)

The NDVI values range between -1 and +1; values approaching -1 indicate low vegetation cover, whereas values approaching +1 clearly indicate dense vegetation. Table 5 and Figure 5 show variations in NDVI values for the study area in northern Basra, where the values ranged from 0 to 0.698. Table 6 and Figure 6 demonstrate the differences in the southern Basra study area, where the values ranged from 0 to 0.401. The classification of Sahebjalal and Dashtekian (2013) for land use based on NDVI values was adopted for the soils of the northern Basra region. Lands with values less than zero, covering an area of 501.53 hectares or 1.45% of the study area, were classified as water bodies. Bare lands, with NDVI values ranging from 0 to 0.15, accounted for 91.32% of the area or 31,557.99 hectares. Areas with NDVI values between 0.15 and 0.30 were classified as having sparse vegetation cover, representing 6.98% of the area or 2,412.31 hectares. Medium vegetation cover (0.30–0.45) constituted 0.25% or 84.74 hectares, while dense vegetation cover (values greater than 0.45) was completely absent, with only 0.06 hectares recorded. In southern Basra, 0% of the area, or 1.51 hectares, was classified as water bodies. Bare land covered 98.51% of the area, equivalent to 4,342.48 hectares. Sparse vegetation areas constituted 1.41% or 620.46 hectares, while medium vegetation cover accounted for 0.08% or 35.89 hectares. These distributions are likely due to the timing of the satellite image acquisition, which coincided with the land preparation period for agricultural cultivation. The limited green areas are attributed to the presence of date palm farms in northern Basra and tomato farms in southern Basra.

Table (5): NDVI Classes and Their Areas in the Northern Basra Region

NDVI Value Range	Class	Area (ha)	% of Total Area
< 0	Water	501.53	1.45%
0 – 0.2	Barren Land	31,557.99	91.32%
0.201 – 0.4	Low Vegetation Cover	2,412.31	6.98%
0.401 – 0.6	Moderate Vegetation Cover	84.74	0.25%
0.601 – 0.698	Dense Vegetation Cover	0.06	0.00%

Table (6): NDVI Classes and Their Areas in the Southern Basra Region

NDVI Value Range	Class	Area (ha)	% of Total Area
< 0	Water	1.51	0.00%
0 – 0.2	Barren Land	43,427.48	98.51%
0.201 – 0.4	Low Vegetation Cover	620.46	1.41%
0.401 – 0.6	Moderate Vegetation Cover	35.89	0.08%

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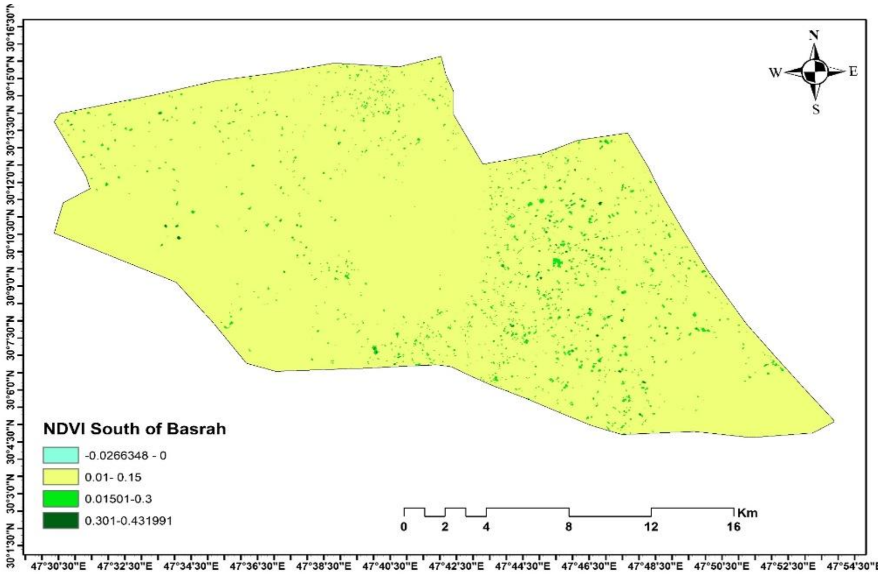

Figure (5): Spatial distribution of the NDVI index in the southern Basra region

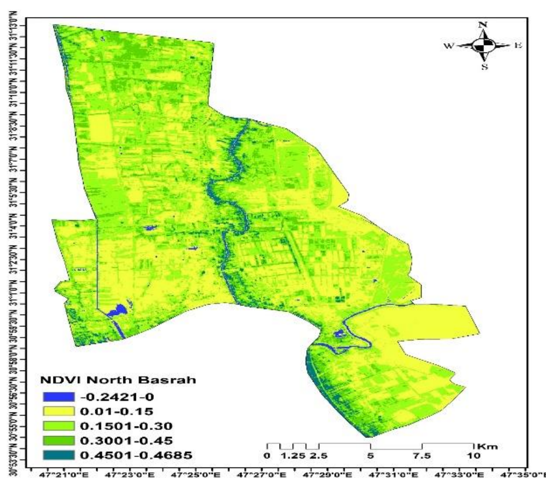

Figure (6): Spatial distribution of the NDVI index in the northern Basra region

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IV. Conclusions

• The highest concentrations were recorded at sites 30 and 4, with values of 4 and 0.32 mg kg^{-1}, respectively, while the lowest concentrations were recorded at sites 21 and 24, with values of 0.56 and 0.02 mg kg^{-1} in the northern and southern regions of Basrah, respectively.

• The remaining values from the other study sites varied between the highest and lowest recorded concentrations.

• Significant correlations were found between copper availability and electrical conductivity in the southern region of Basrah, indicating an increase in available copper with increased conductivity. In contrast, in the northern region, significant correlations were observed between copper availability and both soil pH and organic matter content.

• The spatial variation between the northern and southern Basrah sites is attributed to differences in the studied soil properties.

• The NDVI (Normalized Difference Vegetation Index) values were low due to the timing of satellite image acquisition and sample collection, which coincided with the land preparation and agricultural operation period.

• Most soils in the study area require copper supplementation through fertilization to achieve optimal productivity and maintain food security.

V. Recommendations

It is recommended to apply fertilizers containing copper in the study areas due to the observed deficiency in its available form. Additionally, the use of Geographic Information Systems (GIS) methods and techniques is advised, as they significantly reduce time and effort and provide valuable insights into the spatial distribution patterns of available manganese.

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