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Evaluating Soil Texture and Elemental Composition in Wasit Governorate, Iraq: A Remote Sensing Approach

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Abstract

This study employs remote sensing methodologies to evaluate the texture and elemental composition of soils in Wasit Governorate, Iraq. The research scrutinizes the concentrations of various elements (Na, Mg, P, S, Cl, K, Ca, Al, Si, Ti) and the sodium adsorption ratio (SAR) across different soil textures: Caly, Silty Clay Loam, Silty Clay, and Clay Loam. The investigation delves into how these elements and SAR influence the salinity, sodicity, fertility, and acidity of the soils, thereby affecting their properties and suitability for diverse applications. The study also explores the distribution and variation of these elements and SAR across different soil textures, discussing the potential reasons and implications of this variation. The research concludes that understanding the chemical composition of soils is integral to managing soil health and fertility, necessitating consideration of other aspects of soil health such as soil biology, physical properties, local environmental conditions, and farming practices. The study further analyzes the sediment composition and soil properties of Mesopotamia, a region characterized by clay (41-57%), silt (37-53%), sand (1-13%), and absence of gravel. The research presents data from a random sampling of a geopedological area map, using a table and two figures. The study observes that the percentage of silt increases in the east and decreases in the south, while the percentage of clay increases in the north and south. The research also finds that the mean sand value is 12.26%, the mean organic matter value is 0.607, the mean clay value is 43.87%, the mean heterogeneity coefficient is 3.851, the mean skewness is 0.067, and the mean kurtosis is 0.117. The study indicates that the organic matter content decreases in the southeast, as suggested by the salt extent in the south due to erosion and corrosion processes. This decrease corresponds to an increase in the corrosion factor, which ranges from 0.147 to 0.696. The research discusses the implications and applications of the findings for soil health and fertility, land use and transformation, and agricultural and environmental sustainability. The study concludes that the sediment composition and soil properties of Mesopotamia are diverse and complex, requiring meticulous monitoring and management to maximize their potential and minimize their risks.

Keywords: soil composition, elements, SAR, soil properties, soil suitability, Iraqi soils.

1. Introduction

The fertile soils of Iraq, teeming with life, are a testament to the intricate balance of physical, chemical, biological, and ecological elements that foster biodiversity, water retention, plant growth, and nutrient cycling (1). However, this equilibrium is under threat, as highlighted by Gholamhosseinian et al. (2). Factors such as pollution, waste disposal, deforestation, overgrazing, climate change, land use alterations, and human activities (3) are jeopardizing the quality of these invaluable soils. Iraq has been grappling with significant climatic changes over recent decades. The escalating temperatures and dwindling rainfall have given rise to a plethora of environmental challenges, including droughts, water scarcity, desertification, and diminished crop yields (4). The severity of these changes has led to Iraq being identified as one of the five countries most severely affected by climate change (5). The country is experiencing a declining water supply and accelerating desertification, resulting in the loss of approximately 60,000 acres of arable land annually (6). The Tigris and Euphrates rivers, once the lifeblood of our agriculture, are now confronted with challenges including upstream dams, transboundary disputes, pollution, sedimentation, and climatic unpredictability. These rivers, shared by several nations and vital to our agriculture, are susceptible to mismanagement and conflict (7). The narrative becomes more complex when we consider soil salinity and a condition where excessive sodium or other salt content renders our soil overly saline (8). This can be caused by irrigation with saltwater or overuse of salt-containing fertilizers. Air pollution isprevalent in many Iraqi urban areas due to dust storms, wildfires, power plants, industrial operations, garbage burning, and traffic emissions, poses another significant challenge. This invisible adversary can lead to reduced visibility, acid rain, greenhouse gas emissions, respiratory conditions like asthma and chronic obstructive pulmonary disease (COPD), cardiovascular conditions like heart attacks and strokes, cancer deaths, premature deaths, and the effects of climate change (9). Soil quality is pivotal for both the quantity and quality of food produced, making it indispensable for Iraqi agriculture. Substandard soil quality can diminish crop yields due to toxic levels of contaminants or nutrient deficiencies or imbalances. It can also impact the safety of food for consumption by animals and humans due to pathogens or toxins present in the soil or crops grown in polluted soils (10). The agricultural sector in Iraq is facing substantial challenges due to the degradation of soil quality across different textures and electrical conductivities (11). This degradation is influenced by various factors, including climate change, human activities, and the excessive use of fertilizers (12). These elements may cause the soil to chemically alter, increasing soil salinity, which may adversely affect crop production and groundwater quality (13). Both the environment and agriculture heavily rely on the condition of the soil. However, comprehensive, and systematic monitoring of the chemical changes in Iraqi soils is lacking (15). This knowledge and practice gap hinders the development and implementation of effective soil management and sustainable agriculture plans. Therefore, research on tracking the chemical alterations in Iraqi soils with varying textures and electrical conductivities is urgently needed (16). Another comprehensive review highlighted the different detection methods, types, parts, and applications of remote sensing techniques in soil measurements. It suggested spectral reflectance, which entails satellite remote sensing and other tools based on its global coverage, high spatial resolution, long-term monitoring capabilities, non-invasiveness, and cost-effectiveness (17). A post on Spatial Post mentioned that remote sensing plays a crucial role in soil erosion management. By utilizing satellite and aerial imagery, it enables real-time monitoring and assessment of erosion patterns, helping to identify vulnerable areas (18). Such studies could provide valuable insights into the causes and effects of soil degradation, offering a deeper understanding of the intricate dynamics of soil health. Therefore, the aim of this study is to utilize remote sensing techniques for the assessment of soil texture and elemental composition in Wasit Governorate, Iraq.

2. Material and Methods

Area of Study

The study area, situated in the core of Iraq (refer to Figure 1), is geographically located between 32° 30’ - 32°10’ N latitude and 45° 50’ - 46° 27’ E longitude. This area forms a part of the Mesopotamian plain, a region renowned for its fertile soil and historical importance as a center for agriculture and civilization.

The landscape is predominantly characterized by Quaternary deposits, which are divided into Pleistocene and Holocene deposits as per the 2003 Food and Agriculture Organization (FAO) report. These deposits provide a detailed historical record of the environmental and geological changes that have occurred throughout the Quaternary period. The older, lower stratum represents remnants of the Pleistocene epoch, which lasted from about 2.6 million to 11,700 years ago. This epoch, marked by repeated glaciations or ice ages, resulted in deposits rich in fossils and other remains, offering insights into the plant and animal life of that era. Conversely, the Holocene deposits form the upper, more recent layer, originating from the Holocene epoch that started 11,700 years ago and continues to the present day. As this epoch aligns with the onset of human civilization, these deposits can provide insights into human activities and environmental changes in the recent past.

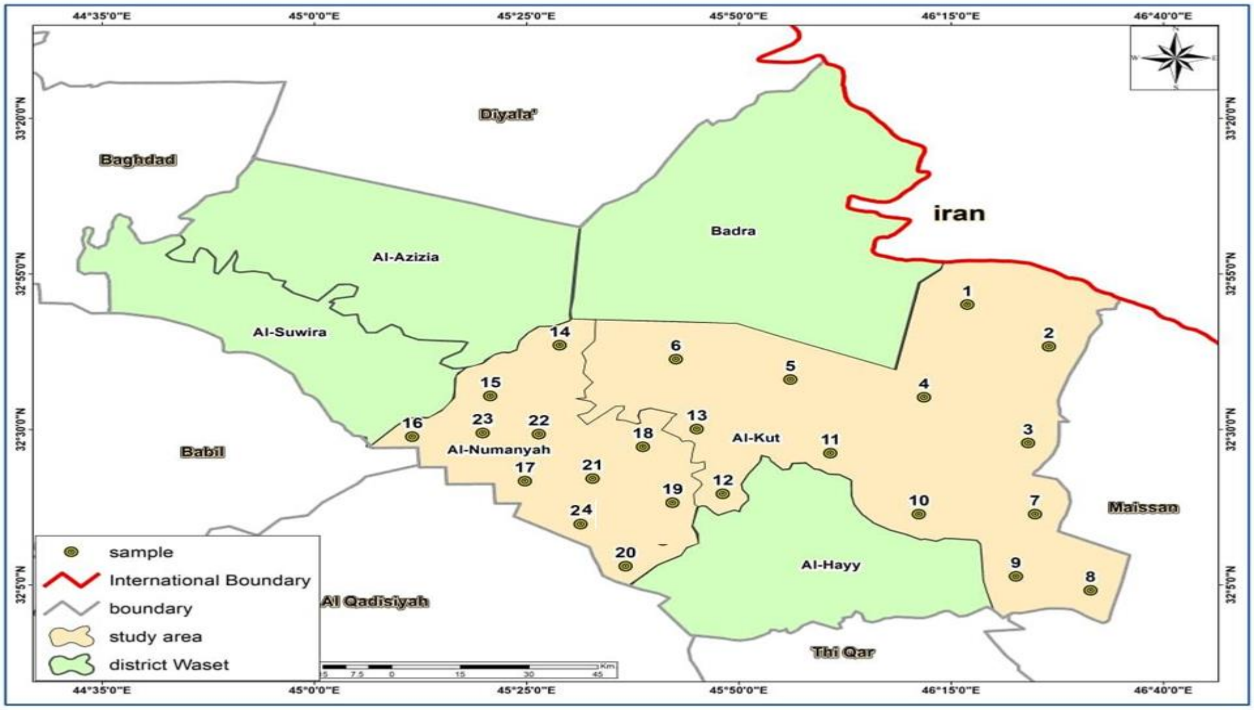

Figure 1. Location map of the study area (Source: DWRW, 2010)

Soil Sampling and Analysis:

In April 2023, 24 soil samples were collected in from two distinct regions within the top 30 cm layer. The samples were stored at 4°C in field moist conditions. The soil texture was ascertained using the hydrometer method [13] and was categorized into eight distinct groups based on varying Electrical Conductivity (EC) values. pH and electrical conductivity were measured in a 1/5 soil/water ratio extract [10]. Available Phosphorus (P) was extracted with sodium bicarbonate and quantified as per a previously described method [17].

Exchangeable Potassium (K), Magnesium (Mg), Sodium (Na), Sulphate (S), Chlorate (Cl), Aluminum (Al), and Titanium (Ti) levels were analyzed by X-ray fluorescence (XRF) spectrometry. The XRF analysis was calibrated against curves from certified reference materials to ensure result accuracy and reliability.

Sodium Adsorption Ratio (SAR) is a key parameter in sodium-affected soil management, indicating water suitability for agricultural irrigation based on the concentrations of main cations. SAR is calculated as:

$$SAR = \frac{Na}{\sqrt{Ca + Mg}}$$

where Na, Ca, and Mg concentrations are in milliequivalents per liter.

The K factor calculation involves various methods (17, 18), approach. The mathematical representation of this method is:

$$K = fp \times Pom \times Sstruc \times fperm \times Pclay$$

where:

- fp: particle size parameter (unitless)

- Pom: percent organic matter (unitless)

- Sstruc: soil structure index (unitless)

- fperm: profile-permeability class factor (unitless)

- Pclay: percent clay (unitless)

To evaluate the statistical significance of radioactivity concentration variations across fields, a Student's t-test was conducted at a 99% confidence level.

3. Results and Discussion

Electrical conductivity (EC) in soil is a key parameter that provides valuable insights into various soil properties. It is sensitive to properties related to both solid and fluid phases, such as soil type, mineral composition, moisture content, void ratio, and conductivity of the pore fluid. Temperature, humidity, and test frequency also have a direct effect on the measured electrical resistivity. The high specific surface area and the presence of electric charges on most particles are responsible for important soil characteristics such as swelling capacity, the ability of the soil to retain water, cation and anion adsorption, and ion exchange. These characteristics can significantly influence the EC of the soil. In the context of soil chemistry, the EC can provide information about the total soluble salt content in the soil. For instance, a high EC often indicates high salinity, which can be detrimental to plant growth and soil health. The type of salts presents in the soil, often determined by the soil's mineral composition and weathering processes, can also influence the EC. Soils rich in sodium or magnesium salts may exhibit different EC values compared to those dominated by calcium or potassium salts. Furthermore, the EC can also be influenced by the soil's moisture content. Water acts as a medium that facilitates the movement of ions in the soil, thereby affecting its EC. Therefore, soils with high moisture content typically exhibit higher EC values compared to dry soils. The role of remote sensing in this context is significant. Remote sensing technologies can provide large-scale spatial information about soil properties, including EC, in a non-destructive and efficient manner. They can help in mapping and monitoring soil salinity levels over large areas, which is crucial for managing soil health and agricultural productivity. Techniques such as satellite imagery, aerial photography, and ground-based sensors can be used to measure soil EC indirectly by capturing the spectral responses of soils and relating them to EC values. However, it's important to note that while EC provides valuable information about soil properties, it should not be used in isolation to make inferences about soil health or suitability for specific crops. Other factors such as soil pH, organic matter content, nutrient availability, and soil texture also play crucial roles in determining soil health and should be considered alongside EC and remote sensing data. This comprehensive approach can help in making informed decisions about soil management and crop cultivation.

The table 1 shows the concentration of different elements (Na, Mg, P, S, Cl, K, Ca, Al, Si, Ti) and SAR in different types of Iraqi soils. the concentration of Sodium (Na) ranges from 0.23 in Silty clay Loam 20.6 to 0.33 in clay 74. This could be due to differences in the mineral composition of the soils, which is influenced by factors such as parent material, weathering processes, and soil formation conditions. Similarly, the concentration of Magnesium (Mg) is highest in Silty clay 14.83 (0.277) and lowest in clay 74 (0.093). Magnesium is a crucial element for plant growth and is often supplied to soils in the form of fertilizers. The variation in Magnesium levels could be due to differences in soil fertility or agricultural practices. The concentration of Phosphorus is highest in Silty clay 14.83 (0.01239) and lowest in clay 74 (0.00425). The concentration of Sulfur is highest in Silty clay L 64.09 (0.4318) and lowest in Silty clay 20.1 (0.04274). The data shows that the concentration of Chlorine (Cl) is highest in Clay 74 (0.9c253) and lowest in Silty Clay 14.83 (0.07894). Chlorine is an essential micronutrient for plants, playing a key role in photosynthesis and osmosis. However, high levels can be toxic to plants, so this could have implications for plant growth in these soils. Potassium (K) is another essential nutrient for plants, involved in protein synthesis and water regulation. The concentration of Potassium is highest in Silty Clay 14.83 (0.8916) and lowest in Clay Loam 20.1 (0.7599). This variation could impact the fertility of these soils and their suitability for different crops. The data also shows high levels of Calcium (Ca) across all soil types, with the highest concentration in Silty Clay 20.1 (8.353) and the lowest in Silty clay loam 64.09 (6.555). Calcium plays a vital role in soil structure and plant nutrition, and its abundance could indicate a high level of soil fertility. The concentration of Aluminum (Al) is highest in Silty clay L 20.6 (0.5449) and lowest in clay 74 (0.4311). While Aluminum is not an essential plant nutrient, it can become toxic to plants in acidic soils. Therefore, the pH of these soils would be an important factor to consider in conjunction with this data. Finally, Silicon (Si) and Titanium (Ti) are both common elements in soils, derived from the weathering of parent material. The concentration of Silicon is highest in Silty clay 20.1 (4.132) and lowest in Silty clay loam 64.09 (3.853). For Titanium, the concentration is highest in Silty clay 20.1 (0.2491) and lowest in Silty clay loam 64.09 (0.2119). These elements are not essential for plant growth, but they can influence soil properties such as texture and water-holding capacity. It’s important to note that the optimal concentration of these elements can vary depending on the specific needs of the crops being grown. Additionally, the availability of these nutrients to plants can be influenced by factors such as soil pH and the presence of other ions in the soil. A high SAR value can indicate that the soil has a higher concentration of sodium relative to calcium and magnesium, which can have adverse effects on soil structure and plant growth. It can also be an indicator of the potential for soil salinity issues and the need for appropriate management practices such as irrigation and soil amendment. Caly: 42±7.6; Silty clay loam: 21.2±8.3, 210.27±28.5; Silty clay: 78.75±18.7, 49.2±35.7, 27.2±35.8; Clay loam: 49.26±51.8, 17.72±32.7. Understanding these SAR values can help in making informed decisions about soil management, irrigation practices, and potential strategies for mitigating the impact of high sodium levels in the soil. It's important to monitor and address SAR levels to ensure optimal soil health and productivity for agricultural or landscaping purposes (17-25). In conclusion, understanding the chemical composition of soils is a crucial part of managing soil health and fertility. It allows for more informed decisions about things like fertilizer application, crop selection, and irrigation practices. However, these decisions should also take into account other aspects of soil health, such as soil biology and physical properties, as well as local environmental conditions and farming practices. The SAR values provided in the table are specific to different soil textures, including Caly, Silty Clay Loam, Silty Clay, and Clay Loam. SAR stands for Sodium Adsorption Ratio and is a measure of the proportion of sodium to calcium and magnesium in the soil.

Table 1. Comparison of soil properties by texture.

Texture	EC ds/m	pH	Na ppm	Mg ppm	P ppm	S ppm	Cl ppm	K ppm	Ca ppm	Al ppm	Ti ppm	SAR
Caly	74±5.2	7.4±0.27	15726±868.4	3884±710.1	21.3±0.79	0.042±0.001	0.40±0.004	0.86±0.007	4226±273.1	0.5307±0.007	0.2491±0.003	42±7.6
Caly	23.1±10.3	8±0.29	4072.7±831.7	1009±212.1	10.9±1.23	0.36±0.002	0.07±0.002	0.89±0.006	1136±248.2	0.5312±0.006	0.2308±0.004	21.2±8.3
Silty clay loam	64.09±6.9	7.92±0.55	32990±963.4	832.3±78.9	12.0±1.53	0.26±0.001	0.11±0.003	0.87±0.006	474.2±75.2	0.5449±0.005	0.2306±0.005	210.27±28.5
Silty clay loam	20.6±5.7	7.7±0.52	9173±924.7	339.3±65.1	18.3±1.49	0.43±0.003	0.64±0.004	0.87±0.006	460.4±61.4	0.4906±0.004	0.2119±0.005	78.75±18.7
Silty clay	48.6±4.9	8±0.34	12667±794.4	2112±169.8	9.9±0.39	0.10±0.001	0.31±0.002	0.84±0.009	1548±171.2	0.5014±0.002	0.2402±0.004	49.2±35.7
Silty clay	20.1±5.1	8.63±0.61	4744.7±519.5	822±77.1	40.9±4.5	0.20±0.009	0.92±0.005	0.76±0.008	944±177.1	0.4311±0.005	0.2113±0.006	27.2±35.8
Clay loam	63.2±6.9	8±0.61	12931.4±310.7	2166±340.1	18.07±3.9	0.041±0.007	0.14±0.007	0.75±0.009	1646±194.2	0.4608±0.002	0.2214±0.007	49.26±51.8
Clay loam	20.1±5.1	7.1±0.52	3307.2±370.1	983.5±111.4	12.48±2.8	0.20±0.004	0.54±0.007	0.81±0.006	1017±164.4	0.4908±0.006	0.2227±0.009	17.72±32.7

Comparative Analysis of Elemental Composition in Various Clay Types

Figure 2 presents a statistical summary of sample data related to soil texture (clay, sand, silt), grain size, and Organic Matter (OM) content. This data is derived from a random sampling of a comprehensive geopedological area map. In addition, the table outlines the normal distribution of the erodibility factor, as illustrated in Figure 2.

The sediment composition in Mesopotamia is as follows: clay (41-57%), silt (37-53%), sand (1-13%), with an absence of gravel. These sediments cover vast, flat areas that lack vegetation. Over time, these fine sediments have accumulated, forming significant deposits.

Within the study area, the percentage of silt increases in the eastern part and decreases in the south. Conversely, the proportion of clay increases in the north and south. Sand is dispersed throughout the region, with the dominant soil texture in the southern part being alluvial clay and mixed clay, as depicted in Figure 3.

The majority of silt measurements ranged with a mean sand value of 12.26% and an average OM value of 0.607. The clay content fluctuated between 47.05 and 40.68%, with a pronounced heterogeneity coefficient ranging between 0.0033 and 7.699%. Skewness and kurtosis ranged between -0.0314 and 0.1657, indicating a substantial distortion by the standard deviation and a deviation from normality.

It is apparent that the organic matter content decreases in the southeastern parts, as demonstrated by the extent of salt in the southern part due to erosion and corrosion processes. This decrease in organic matter corresponds to an increased corrosion factor ranging between 0.147 and 0.696, as referenced in Figure 3.

Improvements and management of soil resources in specific areas can typically influence soil resources, but the magnitude of change can vary based on human intervention. Factors influencing land use and transformation, such as crop cultivation, housing development, insecure land ownership, soil quality, among others, are determined by land management systems.

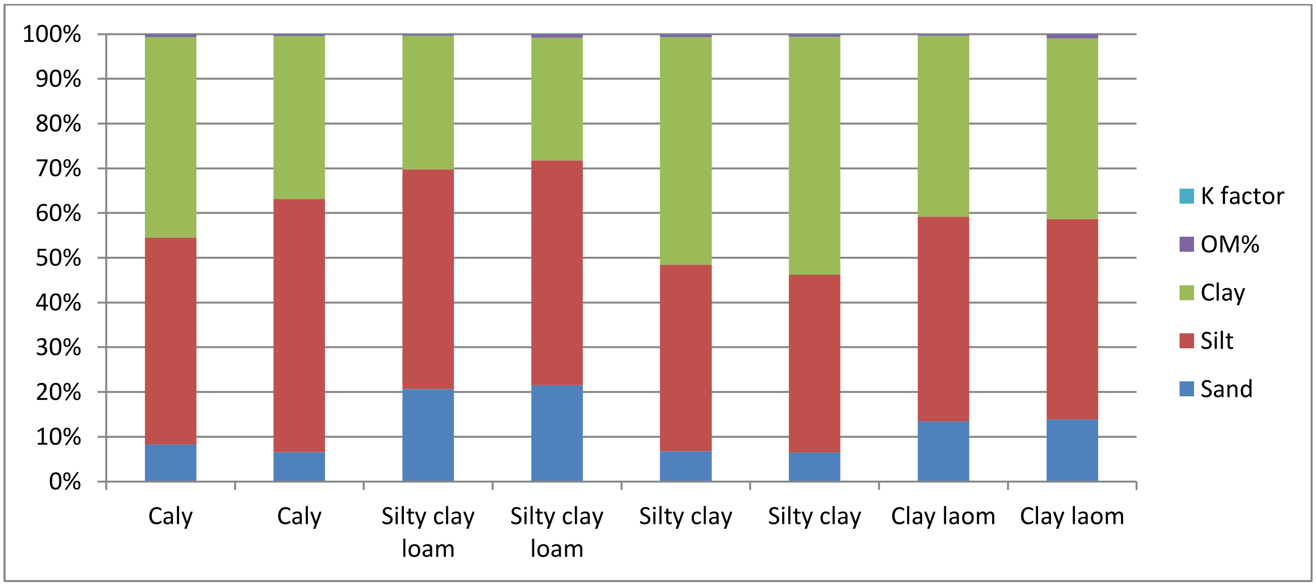

Figure 2. The K- factor correlation and soil properties.

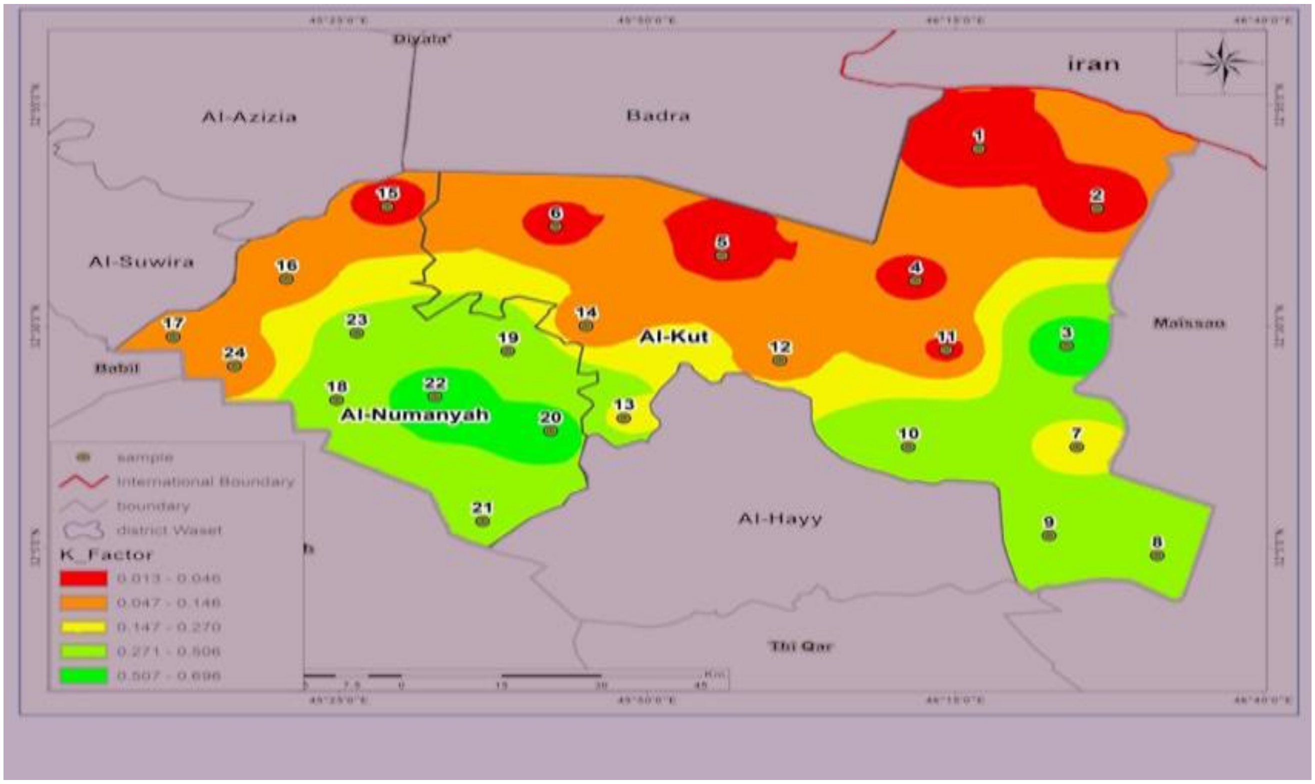

Figure 3. Arc map of K factor.

Conclusion

A thorough comprehension of soil composition, enhanced by a Remote Sensing Perspective, is fundamental for effective soil management. This integrated approach can contribute to maximizing crop yields and advancing sustainable agriculture. The levels of other essential nutrients such as Phosphorus, Sulfur, Chlorine, Potassium, and Calcium differ across soils, affecting their fertility and compatibility with various crops. It's important to note that high concentrations of Chlorine can be harmful to plants, highlighting the necessity for prudent soil health management. The data also underscores the existence of non-essential elements like Aluminum, Silicon, and Titanium, which can alter soil properties such as texture and water retention capacity. However, in acidic soils, elevated levels of Aluminum can be detrimental to plants, stressing the importance of considering soil pH in tandem with this data. The Sodium Adsorption Ratio (SAR), a metric that measures the ratio of sodium to calcium and magnesium in the soil, can signal potential soil salinity problems and the requirement for specific soil management strategies. High SAR values can negatively impact soil structure and plant growth. Essentially, understanding the chemical makeup of soils is a key aspect of managing soil health and fertility. It allows for more informed decisions about fertilizer application, crop selection, and irrigation practices. However, these decisions should also take into account other facets of soil health, such as soil biology and physical properties, as well as local environmental conditions and farming practices. This comprehensive approach to soil management can aid in optimizing crop yields and fostering sustainable agriculture.

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