Iraqi National Journal of Earth Science
www.earth.uomosul.edu.iq

Spatial Distribution Maps of Soil Chemical Properties Using Kriging Model and ArcGIS in Kirkuk City, Iraq

Parzhen Abdullah Mohammed [1*], Qahtan A.M. Al Nuaimy [2], Muntadher Aidi Shareef [3]

[1, 2, 3] Surveying Engineering Department, Technical Engineering College- Kirkuk, Northern Technical University, Mosul, Iraq.

Article information

Received: 09-Sep-2024

Revised: 10-Oct-2024

Accepted: 01-Nov-2024

Available online: 01-Oct-2025

Keywords:
Soil
Chemical Properties
GIS
Interpolation Technique
Kriging Method

Correspondence:
Name: Parzhen Abdullah Mohammed
Email: parzhen.abdullahgs@ntu.edu.iq

ABSTRACT

This study specifically investigates the chemical properties of soils and their distribution across various geographical areas. The Kriging approach, together with Geographic Information Systems (GIS), is utilized to forecast the chemical properties of the soil. A total of twenty-five sampling points were selected among various parts of Kirkuk City. Five soil properties are examined: soil reaction degree or potential hydrogen (pH), total dissolved salts (TDS), gypsum content, sulfate trioxide (SO_3), and organic matter (OM). The chemical analysis indicates that the soil pH is of low alkalinity. This study reveals a limited presence of total dissolved salts between (1.02 - 13.541) %. Moreover, a positive correlation is detected between the gypsum and sulfate concentrations. Conversely, organic matter displays a negative association, but it is most pronounced in the southwestern region. The Kriging technique successfully depicts the spatial distribution of various soil properties in Kirkuk City, showcasing a range of accuracy from satisfactory to exceptional. In addition, a cross-validation method is used to evaluate the relationship between the fundamental and explored chemical properties. The Kriging maps show varying degrees of model fit, with lower root mean square error (RMSE) and higher coefficient of determination (R^2) values of 0.9583, where the higher property is the organic matter. The evaluation of the interpolation methods confirms the dependability of the projected values, thus augmenting our comprehension of the soil properties in the region.

DOI: 10.33899/earth.2024.153439.1351, ©Authors, 2025, College of Science, University of Mosul.

خرائط التوزيع المكاني للخواص الكيميائية للتربة باستخدام نموذج كريجنج و ArcGIS في مدينة كركوك، العراق

پرژين عبدالله محمد [1]* ، **قحطان النعيمي[2]** ، **منتظر شريف [3]**

[1،2،3] *قسم الهندسة المساحية، كلية الهندسة التقنية – كركوك، الجامعة التقنية الشمالية، الموصل، العراق.*

معلومات الارشفة

تاريخ الاستلام: 09– سبتمبر –2024

تاريخ المراجعة: 10– اكتوبر –2024

تاريخ القبول: 01– نوفمبر –2024

تاريخ النشر الالكتروني: 01– اكتوبر –2025

الكلمات المفتاحية:
التربة
الخصائص الكيميائية
نظم المعلومات الجغرافية
تقنية الاستيفاء
طريقة كريجينج

المراسلة:

الاسم: پرژين عبدالله محمد

Email: parzhen.abdullahgs@ntu.edu.iq

الملخص

تتناول هذه الدراسة على وجه التحديد الخصائص الكيميائية للتربة وتوزيعها عبر مناطق جغرافية مختلفة. وقد تم استخدام أسلوب كريجينغ، جنبًا إلى جنب مع أنظمة المعلومات الجغرافية (GIS)، للتنبؤ بالخصائص الكيميائية للتربة. تم اختيار ما مجموعه خمسة وعشرين نقطة لأخذ عينات من بين أجزاء مختلفة من مدينة كركوك. تم فحص خمس خصائص للتربة: تفاعل التربة او الأس الهيدروجيني (pH)، والأملاح الذائبة الكلية (TDS)، ومحتوى الجبس، وثلاثي أكسيد الكبريتات (SO_3)، والمواد العضوية (OM). أشار التحليل الكيميائي إلى أن درجة الاس الهيدروجيني كانت قليلة القلوية. كشفت هذه الدراسة عن وجود محدود للأملاح الذائبة الكلية بين (1.02 - 13.541) ٪. علاوة على ذلك، تم الكشف عن ارتباط إيجابي بين تراكيز الجبس والكبريتات. وعلى العكس من ذلك، أظهرت المادة العضوية ارتباطًا سلبيًا وكان أكثر وضوحًا في المنطقة الجنوبية الغربية. نجحت تقنية كريجينغ في تصوير التوزيع المكاني لخصائص التربة المختلفة في مدينة كركوك، حيث أظهرت نطاقًا من الدقة يتراوح من مرضٍ إلى استثنائي. بالإضافة إلى ذلك، تم استخدام طريقة التحقق المتبادل لتقييم العلاقة بين الخصائص الكيميائية الأساسية والمستكشفة. أظهرت خرائط كريجينج درجات متفاوتة من ملاءمة النموذج، مع انخفاض خطأ الجذر التربيعي المتوسط (RMSE) وقيم معامل التحديد (R^2) الأعلى (0.9583)، حيث كانت الخاصية الأعلى هي المادة العضوية. يؤكد تقييم طرق الاستيفاء على موثوقية القيم المتوقعة، مما يزيد من فهمنا لخصائص التربة في المنطقة.

DOI: 10.33899/earth.2024.153439.1351,

Introduction

The Earth's outermost layer, referred to as soil, consists of fragmented rocks that underwent various chemical, biological, and environmental influences, such as weather and erosion. The rock composition deviates from its basic elements as a result of differences in the interactions occurring among the Earth's four surfaces: the lithosphere, hydrosphere, atmosphere, and biosphere (Sulyman et al., 2020). Minerals and organic matter in liquid and gaseous forms, along with porous particles that hold air and water, make up soil. Soil research focuses on the physical interactions, development, chemical and biological activities, and the dynamic nature of soil. Pedology specifically examines soil as a vital source of life, structure, and substance (Sulyman et al., 2020). The importance of soil varies depending on the community. Farmers perceive soil as a disintegrated region on the Earth's surface that sustains plant and agricultural development. Geologists believe that residual substances derived from the parent rock stimulate root growth. Engineers posit that soils are composed of terrestrial constituents overlaying the bedrock, encompassing liquids, gases, and mineral particles (Taqi et al., 2016). The geotechnical qualities of soils are the most critical aspect for developing exceptional engineering designs (Ahmed et al., 2022). Soils serve a vital function in the urban environment and have both direct and indirect impacts on people's quality of life (Ahmed et al., 2022). For planning and decision-making purposes, it is essential to know the topography, geographic range, and origin of polluted municipal soils (Raheem et al., 2022). Data on land use and cover are crucial for numerous reasons, including but not limited to planning, decision-making, health, basic human needs, and sprawl (Hasan et al., 2021). The development of agricultural policies, soil management, land use, and environmental impacts all depend on a precise understanding of soil quality and variability. Indeed, inadequate legislation and regulation due to a lack of such information might hasten environmental degradation and the emission of carbon dioxide into the air (Chagas et al., 2016). Soils exhibit a significant geographical diversity due to the combined effects of physical, chemical, and biological factors at different strengths and magnitudes. Understanding geographical variation in soil quality is important for different fields, such as field trial studies and precision agriculture (Almasi et al., 2014). The agricultural, ecological, and environmental groups must have a firm hold close at the dispersion of high-quality soil indicators. Soil surveys can create maps that display these spatial distributions. Traditional methods, such as laboratory analysis and subject surveys, can be quite time-consuming and expensive (Salahalden et al., 2023). Geostatistics, a subject of implemented facts, is essential for characterizing the spatial residences of diverse features and objects, particularly soils. Soil planning and opinions are in their infancy with the use of spatial analysis because of the complexity of soil attributes (Salahalden et al., 2023; Liao et al., 2013). One of the most important methods of obtaining information in this field is the creation of soil maps by spatially transmitting soil quality measurements obtained from specific locations (Reza et al., 2010). If the spacing among samples is sufficient to capture the variability at the perfect scale, geostatistical methods can produce accurate estimates at locations without data collection. Spatial prediction strategies, also called spatial interpolation, use geographical coordinates to calculate an estimate for a property in a specific area by means of considering nearby property statistics and applying a weighted average (Reza et al., 2010). Geographic information systems (GISs) are very powerful tools for locating, showing, and analyzing statistics and are topographically referenced (Ahmed et al., 2022). Storing records and information in a geographic information system (GIS) is crucial for developing models and simulations that appropriately depict how soil will respond to or forecast particular soil attributes in a particular place. Characteristics include gypsum content, total soluble salts (TDS), soil reaction degree (pH), sulfate trioxide (SO_3), and organic matter fractions. This part of information that is useful in soil classification, determines soil quantitative changes, and predicts new traits (Merza et al., 2023). Recent research has shown that the use of GIS technology has a significant impact on the quality of land management. Furthermore, GIS techniques provide an efficient way to explore, manage, and retrieve data to improve the understanding of geographic information (Qader et al., 2023).

This study uses the geographic information system (GIS) techniques to map the geographic areas in Kirkuk, which demonstrates the valuable role of GIS in the collection, presentation, and evaluation of topographically referenced data (Raheem et al., 2022). Due to the lack of soil-sampling data, this technology simplifies the process by eliminating rather than forcing the need for extensive outdoor soil sampling and laboratory analysis prediction of soil properties based on past observations (Pande et al., 2022). The primary purpose of this study is to use the Kriging technique of GIS utility to create a map that shows the chemical properties of the surface soil distribution of Kirkuk. We used pass-validation strategies to determine the connections between fundamental and investigated chemical functions. This enables us to determine how well the Kriging method works in this situation. The study aims to enhance understanding of soil properties and spatial variability in Kirkuk, aiding in land management and environmental planning. It analyzes surface soil's chemical properties to understand its nutrient content, plant growth support, and overall quality for agricultural and environmental purposes. Surface soil, the topmost layer, absorbs nutrients from plants and is affected by environmental changes and human activities. Analyzing its properties helps improve soil quality, agricultural productivity, and environmental sustainability, enabling informed decisions for researchers and farmers.

Soil chemical properties, such as pH, organic matter content, gypsum content, TDS ratio, and sulfate content, provide valuable insight into soil behavior and potential industrial applications. Research on these properties helps to determine the suitability of land for industrial problems (Ali et al., 2023).

Potential of hydrogen (pH) is a measure of the acidity or alkalinity of a solution, determined by the inverse logarithm of the concentration of hydrogen ions per molecule. The pH of the soil significantly affects plant development and nutrient availability. The typical pH range for soil testing is 4–10. To alter the pH, alkaline substances such as granite or limestone, or acidic substances such as sulfuric acid can be introduced. Several factors that influence the pH of soil are the concentration and presence of salts, carbonate ions, and dissolved carbonate in water (Sulyman et al., 2020; Al-Abbas and Jinnah, 2019).

Sulfate trioxide (SO_3) is a naturally occurring chemical compound in its purest state; one can readily synthesize it. Humans' presence on land and in the atmosphere has a significant impact on its survival of the natural surroundings. Sulfur in this substance primarily originates from the erosion of evaporated deposits, but it can also originate from rocks, minerals, and volcanic activity (Salahalden et al., 2024b).

Gypsum and other soils containing oxides that can dissolve easily when they come in contact with groundwater. Gypsum can undergo leaching, which can impact soil properties. A gypsum content exceeding 5% might adversely impact soil quality. Several factors influence this threshold, including salt concentration, soil type, particle size distribution, and gypsum fineness. For soil to perform optimally, it is essential to maintain the gypsum content at the appropriate level (Sulyman et al., 2020; Salahalden et al., 2023).

Organic material is the natural material ratio as well. The soil acidity, composition, temperature, and water dispersion influence the natural material concentration. Organic matter (OM) can be classified into two categories: unspoiled or partly degraded plant, animal, and humus stays, a colloidal substance that is more resilient to further degradation due to decomposition. Both styles of soil contribute to its bodily qualities (Balasubramanian, 2017).

Total dissolved salt ratio represents the solubility of salts in water encouraged through various parameters, which include temperature, CO_2 levels, evaporation, moisture, pH, and chemical composition. Together, these elements determine the total dissolved salt ratio. The salinity ratio measures the share of water-soluble salt in soil compared to the overall quantity (Salahalden et al., 2024b).

Study area

Location and geologic setting of the study area

The study area is located within the city of Kirkuk, located in northeastern Iraq as illustrated in Figure 1, at 35° 28′ 5″ N latitude and 44° 23′ 31″ E longitude (Omar et al., 2014 b; Raheem et al., 2022). Kirkuk is situated in the northern region of the Kirkuk Plain at an elevation of approximately 340–360 m above sea level. It is known for its prominent geographical features, such as the Baba Dome, Hamrin Formation, and Lower Zab River (Omar et al., 2014 a). The Kirkuk structure delineates the city's northern and eastern boundaries, while the Hamrin structure demarcates its western and northern margins. Kirkuk City is renowned for its copious natural minerals and oil resources due to its strategic position between the mountainous north and the flat southern and southwestern areas of the study area. This province is oil-rich and produces some of the world's highest-quality oils (Omar et al., 2014 a).

Climate of the study area

The research area is subject to a semiarid and Mediterranean environment, which is characterized by scorching and arid summers, as well as frigid winters. Most of the precipitation falls from December to March, while the summer months get minimal or no rainfall. The climate is greatly influenced by temperature, which may reach a maximum of over 48 ℃ in the summer and plummet to a minimum of -1 ℃ in the winter, as documented by Muhaimeed and Al-Hedny (2013).

Geology of the study area

Kirkuk City comprises various geological strata dating from the middle to upper Miocene. The geological formations discovered in Kirkuk are listed in chronological order from oldest to youngest as Fatha, Injana, Mukdadiya, and Bai Hassan (Jabbar, 2015). During the Pliocene, Earth underwent notable tectonic activity, resulting in the formation of geological formations such as Kirkuk, Bia-Hassan, Khabaz, Jambur, and Hamrin, as well as a wide syncline known as the Kirkuk-Hawija plain. Erosion occurs in regions with highly resistant rocks, resulting in the transport and deposition of eroded materials in lower places (Ismail et al., 2024). The geography of Kirkuk is predominantly characterized by relatively even and level terrain, with uniform elevation levels in the northern area situated at a distance of 786 kilometers from the Arabian Gulf. The Bor, Jambor, and Kirkuk anticlines indicate that structural forces shaped the elevated landscape. The Kirkuk area is located in a narrow space between the Sirwan (Diyala) River to the southeast, the Hamrin Mountains to the south, the Zagros Mountains to the northeast, and the Zab and Tigris Rivers to the west (Omar et al., 2014 a). Other Iraqi cities exhibit unique characteristics in terms of their environment and topography. The research region encompasses a diverse topography consisting of plateaus, plains, valleys, and mountains. The geological aspects, namely the wind patterns, temperature levels, and rainfall amounts, all serve as indicators of the climatic zone (Hasan et al., 2021).

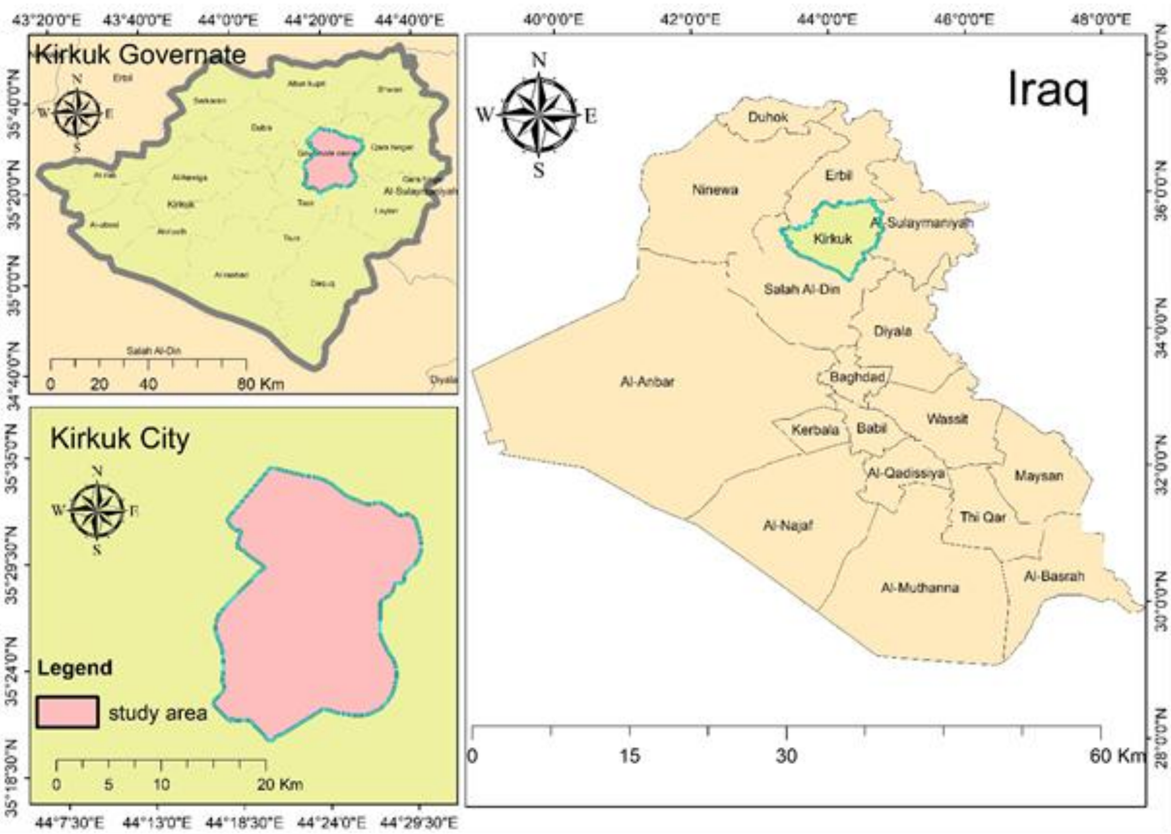

Fig. 1. Map of the study area in Kirkuk, Iraq.

Materials and Methods

Data sampling and laboratory analysis

A comprehensive study was conducted across the entire city to ascertain the composition and properties of the soil at all the surveyed locations throughout all areas in Kirkuk in October 2023 as a preliminary step to determine the locations for soil sampling and installation. Then dug the surface to a depth of 20–30 cm to acquire soil samples. Each collected sample was at intervals of 2 km, meticulously labeled, and then stored in assigned containers. A total of 25 samples were collected. The sample locations are carefully recorded using a global positioning system (GPS) device to ensure accurate spatial data collection at different locations in Kirkuk (Fig. 2). After the field project completion, the soil samples were subjected to laboratory analyses to evaluate the chemical composition of the samples. The laboratory quantified the chemical properties of the soil samples, including pH, organic matter content, gypsum content, total dissolved salts (TDS), and sulfate content. The pH is measured using a multi-parameter PCTestr 35 devices, which provides the hydrogen ion concentration. The total dissolved solids of the clay samples are quantified using a portable TDS meter. The determination of gypsum content is conducted following the British Standard method B.S. 1377-3/2018, wherein the samples underwent a baking process at 150 °C. The proportion of organic matter is determined using an oven incineration at 700 °C, facilitating the assessment of the organic material ratio. These techniques have enabled accurate chemical analysis of soil samples in the laboratory.

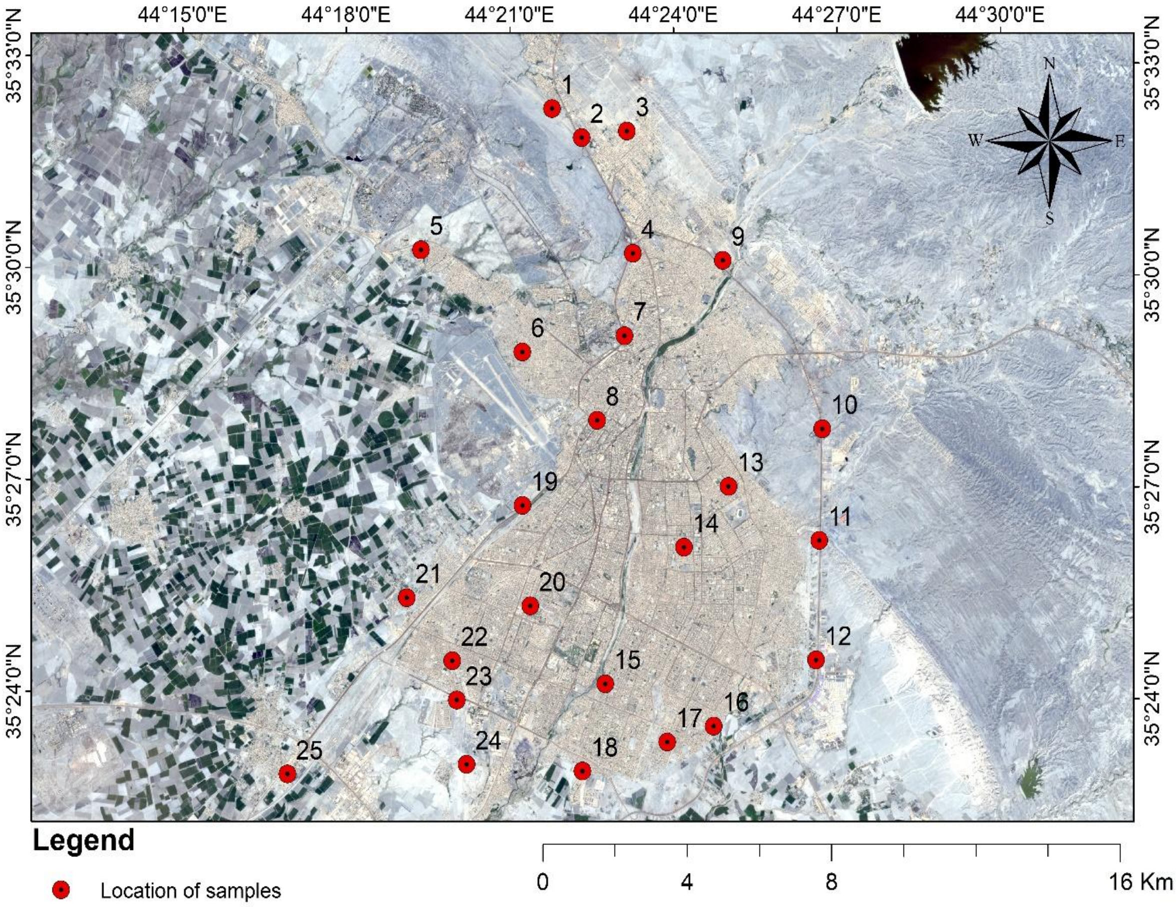

Fig. 2. Surface soil sampling locations in Kirkuk City.

ArcGIS maps and Kriging interpolation

The process of assembling geographic data regularly considers the maximum expensive and time-consuming issue of creating a database for GIS programs (Chica-Olmo et al., 2019). This approach includes two fundamental categories of procedures: fact integration and assembly. Information integration involves translating facts while preserving their integrity, whereas information collection involves new data, including GIS (Chica-Olmo et al., 2019). The Kirkuk Construction Laboratory at TCK University, where the substances were checked, served as the primary statistical supply for this observation. We also collected subject observations to investigate the sites and documented the chemical characteristics of the soil for 25 special samples at distinct depths. We also recorded and formatted each research site and laboratory data in an Excel spreadsheet. Then, we created a shapefile or thematic map using the tools in ArcMap. The Kriging method served as an interpolation method in this study, as shown in Figure 3. We used this method to project the surface through the collected data points, enabling us to visualize and construct the distribution of soil properties within the entire study area.

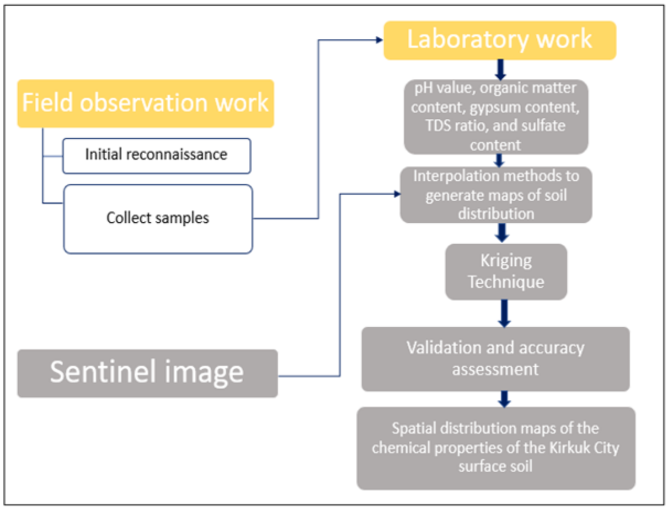

Fig. 3. Flow chart of the applied methods.

Interpolation techniques

The geostatistical method is a spatial distribution and variable analysis method derived from traditional statistics (Morgan et al., 2017). It uses global and local projectors to represent space, with global interpolation using all sample point data in the study area and local interpolation relying on neighboring data points (Tan and Xu, 2014). The input method calculates feature values at locations where measurements are not recorded, transforming discrete data into continuous fields for spatial patterns analysis (Karydas et al., 2009).

The Kriging approach is a frequently used interpolation technique that involves guessing values at places where data are not always available. This estimation is primarily based on the distances and values of nearby sampled points. Kriging is a geostatistical interpolation approach that employs a variogram fashioned more by means of the spatial association of statistics than by actual values. When high-quality variogram models exist, we use records-pushed weighting functions to determine the fine Kriging weights for the most suitable interpolation. These weights are designed to limit any bias closer to the entry values (Arun, 2013). This is calculated by Eq. (1):

$$\gamma(h) = \frac{1}{2n}\sum_{i=1}^{n}[Z - Z(x_i + h)]^2 \qquad (1)$$

where: xi and $xi + h$ are sampling sites separated by a distance h; $Z(x_i)$ and $Z(x_i+h)$ are the measured values of the variable Z at those coordinates (Yao et al., 2013; Kravchenko and Bullock, 1999).

Results and Discussion

Table 1 provides a summary of the chemical properties of the analyzed and measured soil in the region based on a statistical analysis of 25 sampling locations. To predict the distribution of soil properties in Kirkuk City, the Kriging interpolation technique is used. Data are collected from 25 locations to determine five characteristics of the soil: pH, organic matter, total dissolved salts, gypsum, and sulfates. The soil properties are trained using 70% of the sample data. Validating the created map using these data is essential. Thirty percent of the soil samples is used as testing data to calculate the RMSE and determine the difference between the actual and anticipated values. By GIS, we construct digital maps using Kriging techniques and a surface approximation algorithm based on soil properties at known sites. We used Kriging to divide these chemical properties into five distinct regions: very low, low, medium, high, and very high. We represent these regions using a color scale, where brown signifies lower proportions and dark blue indicates larger proportions. This study investigated the distinctive spatial distribution properties of Kirkuk city.

Table 1: Chemical properties of soil in Kirkuk.

	No.	Symbol	Place	x	y	pH	T.D.S %	$CaSO_4.2H_2O$ %	SO_3 %	OM g/kg
Training data	3	AA6	Shuraw 6	444333	3932357	7.1	2.98	2.7519	1.2799	6.0922
	4	B	Rahimawa	444496.69	3929155.94	7.3	9.85	5.4	2.5	6.2
	6	C	Failaq	441434.6047	3926576.302	7.4	5.25	1.2	0.55	3.5
	7	D	Almas	444265.5329	3926996.9	7.3	5.1	1.2	0.55	9
	8	DD	Shara jumhurya	443508.3698	3924784.891	7.2	11.25	1.2	0.55	7
	9	E1	Sulaymania-Hawli road 1	446991.068	3928971.867	7.7	1	3.9	1.84	6.3
	10	EE2	Hawli road 2	449748	3924566	7.1	7	4.3139	2.0065	6.7065
	13	H2	Shurja 2	447147.6232	3923057.415	7.1	13.6	0.63	0.3	6
	14	III	Hiwa	445913.8193	3921466.135	7.3	8.95	2.2	1.02	5
	15	K2	Al-asra u mafqouden 2	443736.4879	3917891.156	7.5	3.7	2.5	1.19	5.6
	16	L2	Al-zoura 2	446739.0241	3916783.45	7.6	2	3.5	1.6	6
	17	LL	Aso - Al-aofq	445451.5139	3916367.723	7.7	1.3	5.5	2.558	9.03
	18	MMM	Kubani	443104.3476	3915603.726	7.5	2.8	3.92	1.82	8.9
	19	NN	Hamzali	441438.1844	3922557.757	7.5	3	0.8	0.38	11
	20	PP	Hay Wasti	441657.2063	3919930.785	7.7	1.6	5.1	2.37	9
	21	QQ	Hay badr	438232.0373	3920143.799	7.5	1.9	0.99	0.4	10
	23	RR	Madynati	439621.7209	3917463.099	7.6	3.85	0.04	0.01	9
	24	SS	Sayada	439890.8608	3915780.895	7.6	3.15	0.2	0.09	11
Testing data	1	A3	Sekanyan 3	442259	3932941	7	4.42	2.9823	1.3871	5.5051
	2	AA2	shuraw 2	443078	3932185	7.1	4.59	3.0919	1.4381	4.5866
	5	BB1	Amal shabi 1	438624.8501	3929249.512	7.4	0.95	0.4	0.19	5
	11	F2	Hawli-Panja Ali Road 2	449664	3921642	6.8	4.22	3.9632	1.8433	6.0574
	12	F3	Hay Senaay-Panja Ali 3	449575.8788	3918515.922	7.6	2.05	2.5	1.16	3.4
	22	R	Wahid Huzayran	439492.7951	3918495.629	7.4	3.5	3	1.39	8.2
	25	T	Hay senaay old	434925.7054	3915527.129	7.6	2.5	0.1	0.048	12

Spatial analysis based on the Kriging method

Figure 4 shows that soil samples taken from a depth of 20–30 cm in different areas of Kirkuk have pH values ranging from 7.1 to 7.7. The areas with the best pH values are Sulaymania-Hawli Road, Hay Wasti, and Aso. On the other hand, the areas with the lowest pH values are Shuraw, Shurja, and Hawli Road. This suggests a trend toward increasing pH inside the northern and southern parts of the Kirkuk Mountains. Our investigation reveals a decreased pH in comparison to the pH measurements performed for the soil of Kirkuk City in 2020 (Sulyman et al., 2020), which range from 7 to 9 as determined by an evaluation with earlier research. Acid rain, excessive use of chemical fertilizers, mineral leaching, and deforestation may also contribute to a lower soil pH in the same regions. These components can lead to soil acidification, resulting in a reduction in pH.

Figure 5 displays the distribution of total dissolved salts (TDS) derived from the Kriging analysis. The TDS rate ranges from 1.02% to 13.541% in Kirkuk City. Shurja has the highest TDS value. Kirkuk, Sulaymania-Hawli Road has the lowest TDS, but it decreases as traveling north and south. Our results are lower than the results of Sulyman et al. (2020) for Kirkuk City, where the percentage of soluble salts ranges between 44.3 and 847.5%. The release of ions during weathering processes and atmospheric deposition from several sources can result in increased soil salinity.

The gypsum concentration ($CaSO_4.2H_2O$) in Kirkuk City ranges from 0.04% to 5.5% as shown in Figure 6, which indicates that the Aso area has the greatest proportion of gypsum (5.5%) and has gypsum layers in a variety of places and strata. Madynati, on the other hand, has the lowest percentage. The findings show that the gypsum ratio is minimal in every sample. This low gypsum ratio is the result of rain or the Khasa River washing the sediment in Kirkuk City. There is an increase in gypsum in the northern and southeastern regions as a result of the gypsum layers' erosion present in the Fatha Formation, and these values decrease as one moves away from the source site of the formation. The National Center for Structural Laboratories conducted soil research within the southern Saylo area of Kirkuk and compared the effects with those of previous studies. These findings confirmed that the prevalence of soil gypsum ranges from 0.09 to 67.4% (Sulyman et al., 2020).

The sulfate concentrations range from 0.01% to 2.558%. Figure 7 shows that the soil composition at all the tested sites is low in SO_3. The Aso region had the highest value (2.558), while the Madynati area had the lowest value (0.01). In comparison to earlier research, the Kirkuk soil study (Sulyman et al., 2020) revealed that the observed sulfate amounts range from 2.05 to 4.57%.

Figure 8 displays the distribution of organic compounds as determined by the Kriging study. The organic matter content of Kirkuk City ranges from 3 to 11 g/kg. In Failaq, the organic matter is lower, but in Hamzali and Sayada, it is greater. The results of our study agree with the study of the researchers of Alhashimi et al. (2021), where the recorded results of their research were (0.8-4.1) g/kg. The high organic matter content in the southwest of Kirkuk region's red clay soil is attained by several conditions, such as dense vegetation cover, humid environment, clay soil, organic fertilizers, minimal erosion, sustainable land management, and microbial activity. These characteristics enhance organic matter formation and facilitate organic decomposition, preserving moisture and nutrients, and contributing to soil fertility preservation. Frequent application of organic fertilizers enhances organic matter content, while little erosion aids in the preservation of accumulated organic matter. Sustainable land management preserves and improves organic matter levels, whereas microbial activity expedites the degradation of plant leftovers. Fine-textured soils, such as clay and silty loams, frequently contain more organic matter than coarser-textured soils such as sands and sandy loams.

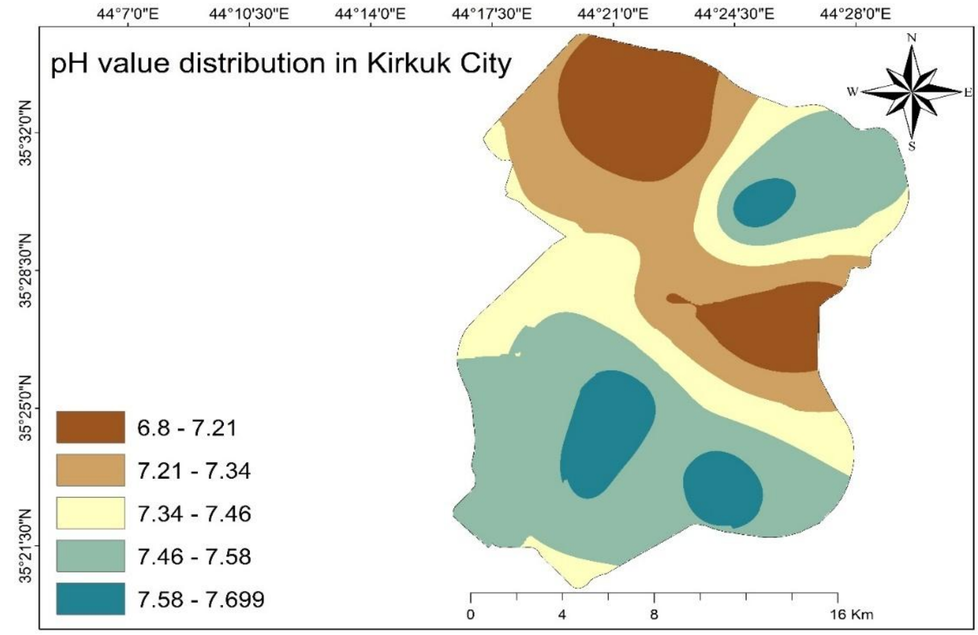

Fig. 4. Kriging representation of the pH distribution

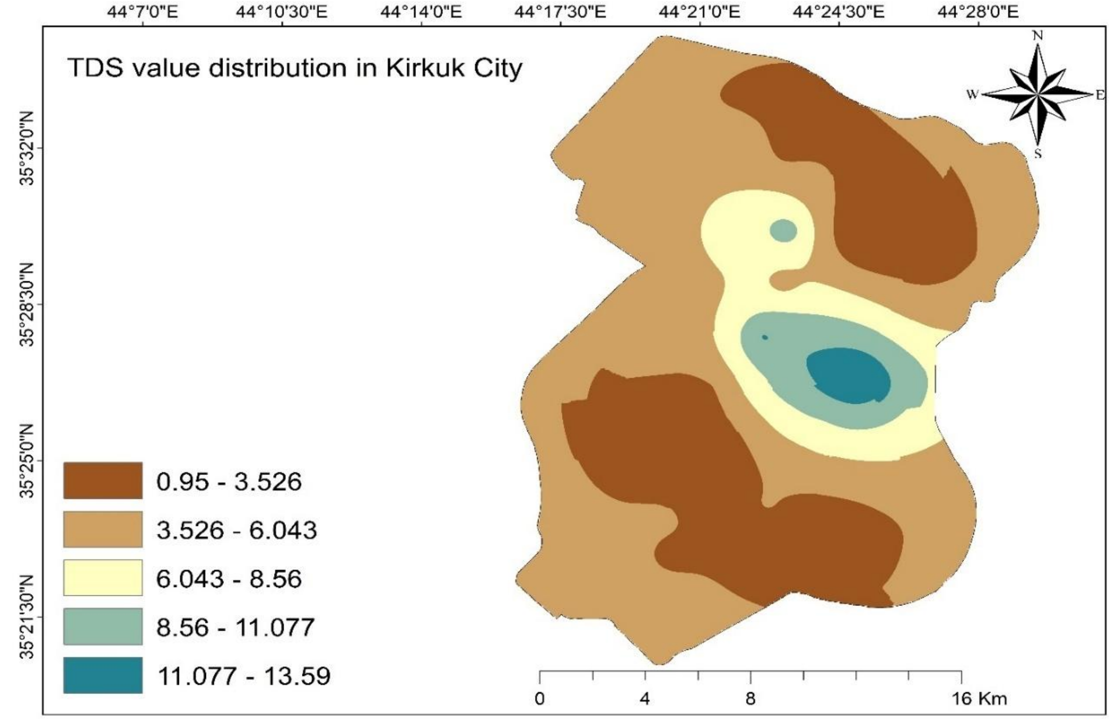

Fig. 5. Kriging representation of the total dissolved salts distribution.

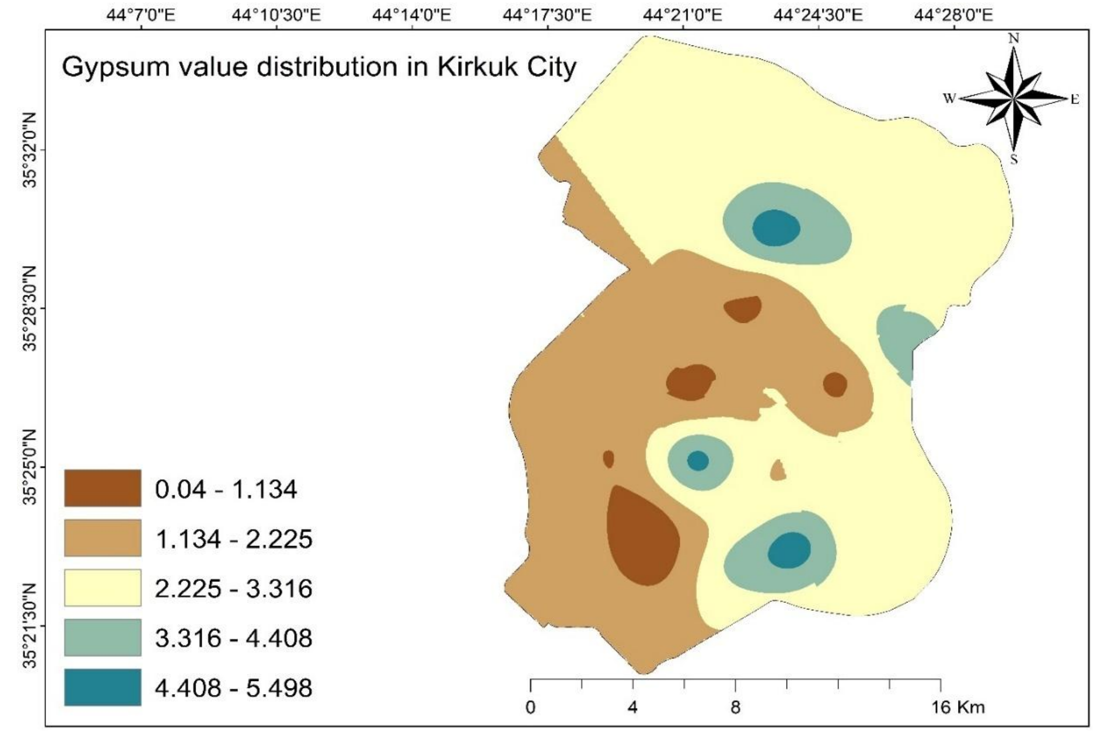

Fig. 6. Kriging representation of the gypsum distribution

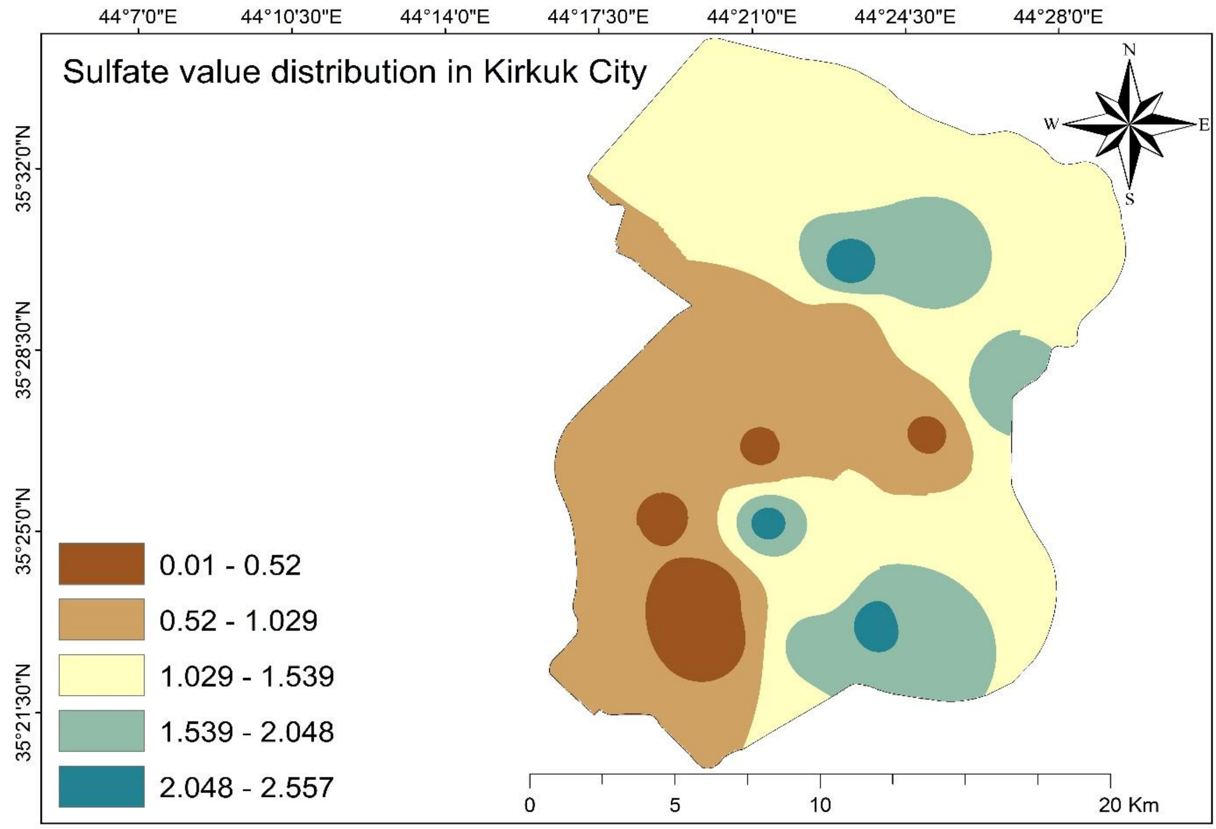

Fig. 7. Kriging representation of the SO_3 distribution.

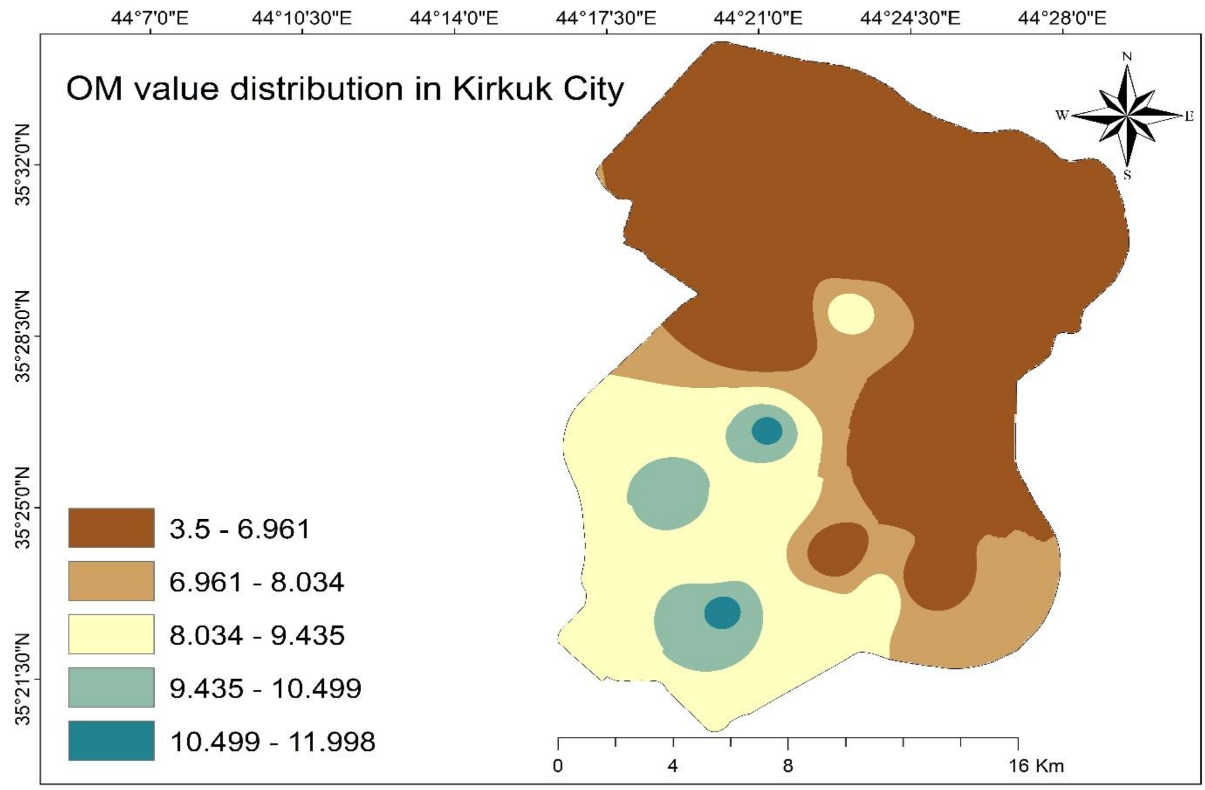

Fig. 8. Kriging representation of organic matter distribution.

Cross-validation

To verify the precision of the Kriging-based total maps illustrating the chemical traits of the Kirkuk soil, a dataset comprising 30% of the soil samples is used (Salahalden et al., 2024a). The objective is to evaluate the consistency among the actual area values, and the values are then used for Kriging. We use a go-validation approach to evaluate the most effective interpolation method. The process includes quickly comparing the estimation technique by way of carrying out checks at modern sample websites, except for a pattern price at a particular place, and estimating it based on the remaining samples. We iterate this method for all on-hand samples and use statistical evaluation to juxtapose the resulting actual and envisioned values. This approach aids in assessing the accuracy of every interpolation method by computing the discrepancy between the actual and predicted values (Ding et al., 2011). To examine various interpolation methods, we use R-squared (R^2) and the root imply squared error (RMSE) (Eq. (2) to evaluate the differences between the anticipated and acknowledged information (Shit et al., 2016).

$$\boldsymbol{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\{z(x_i) - \hat{z}(x_i)\}^2} \qquad (2)$$

where: $\hat{z}(x_i)$ is the predicted value; $z(x_i)$ is the observed (known) value; N is the number of values in the dataset (Morgan et al., 2017; Robinson and Metternicht, 2006).

According to Chicco et al. (2021)**,** better prediction accuracy is shown if the chemical attributes' root mean square error (RMSE) is low and R^2 is high. The RMSE varies from 0.120048 to 0.963811, and the Kriging R^2 varies from 0.3725 to 0.9583. The results of the RMSE and R^2 are shown in Table (2).

Table 2: (RMSE) and R² for maps.

Chemical properties	RMSE	R^2
pH	0.120048	0.5522
TDS	0.721159	0.7836
Gypsum	0.963811	0.6098
SO_3	0.539046	0.3725
Organic matter	0.815576	0.9583

Conclusion

Kirkuk City has shown the significant potential of geographic information systems (GIS) and geostatistical strategies for determining and spatially evaluating diverse soil chemical trends. The task sought to beautify geotechnical and engineering tactics in the region by amassing and analyzing 25 soil samples. Five cartographic representations are produced to illustrate the spatial arrangement of critical soil traits consisting of pH, gypsum, standard dissolved solids (TDS), SO_3, and organic matter at some locations in Kirkuk City. The Kriging technique is modified to show easy spatial distribution styles, emphasizing numerous asset compositions in unique sectors of the study area.

Chemical analyses reveal that the pH values in the southern and northeastern regions range from 7.1 to 7.7, indicating that the soil in the study area is of low alkalinity. A higher pH suggests a greater soil base, which reduces the dissolution of gypsum and calcium carbonate.

Soil salinity has a significant impact on agriculture because it reduces crop yields through several processes, such as lower osmotic potential, difficulty in water extraction, toxicity caused by particular ions, imbalance in plant nutrition, and changes in soil tilth and permeability. The concentration of soluble salts ranges from 1.02% to 13.541%. The release of ions during weathering processes and the deposition of substances from the atmosphere caused these variations in the amount of dissolved salts in different locations.

We observed a positive relationship between gypsum and sulfate, with gypsum contents ranging from 0.04% to 5.5% and sulfate contents ranging from 0.01% to 2.558%. Gypsum and sulfate are present in the northern and southeastern regions, respectively. In these regions, rock blocks erode, and gypsum and sulfate are deposited.

The organic matter content ranges from 3.5 to 11 g/kg, with the highest percentage occurring in the southwestern region, likely due to the presence of agricultural areas. We observed a negative correlation between organic matter and the contents of gypsum and sulfate.

The Kriging maps for chemical attributes have coefficients of determination (R^2) ranging from 0.3725 to 0.9583. Predictions with higher values are more accurate, indicating that the evaluated components are well predicted. Additionally, the root mean square error (RMSE) for the Kriging maps varies from 0.120048 to 0.963811, with smaller values indicating more precise predictions.

In general, GIS methods have shown great efficacy in modelling and measuring the chemical attributes of the soil in the study area. Kriging interpolation is useful in collecting and counting information and predicting what is missing.

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