Article

Analyzing Soil Composition and Suitability for Agriculture in Mosul Using XRD and MED-XRF Techniques

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Abstract

Background: This study investigates the soil composition and agricultural suitability of various locations in Mosul, Iraq, utilizing advanced analytical techniques, including X-ray diffraction (XRD) and portable X-ray fluorescence (MED-XRF).

Materials and Methods: Soil samples were collected from multiple sites, revealing a diverse range of textures, including silt loam, sandy loam, and sand. The XRD analysis identified key clay minerals such as montmorillonite, kaolinite, smectite, illite, and chlorite, which play a crucial role in determining soil fertility and water retention capabilities.

Result: The results indicated that loam soils, particularly in area A4, exhibited optimal conditions for agriculture due to their superior nutrient-holding capacity and water retention properties. In contrast, sandy soils in areas A2 and A3 demonstrated good drainage but lower nutrient retention, highlighting the variability in agricultural potential across the region. The MED-XRF technique was employed to assess elemental concentrations, showing that most elements fell within regulatory limits, thus indicating minimal contamination risks. However, the analysis revealed variability in precision for certain heavy metals, necessitating further calibration for enhanced accuracy. Geographic Information System (GIS) modeling was utilized to synthesize spatial data, facilitating the creation of agricultural land suitability maps.

Conclusion: The findings underscore the importance of regular soil assessments and advanced analytical methodologies in optimizing agricultural practices and promoting sustainable land management in Mosul.

Keywords: pXRF Analysis, Soil Types, Agriculture Suitability, Soil Preparation, and Elemental Analysis.

1. Introduction

The main aim of agricultural land suitability analysis is to find suitable areas to produce crops based on the characteristics and adversity of soil, climate, rainfall topography and socio-economic conditions to fulfil sustainable agriculture as well as overall global food security objectives. Previous methodologies applied for land suitability assessment include machine learning algorithms [1], fuzzy inference systems [2] and weighted linear combination methods among many others [3]. These methods provide a more objective, automatic and time-effective way of crop suitability assessment than traditional techniques that derived from Geographic Information System (GIS) based multicriteria analysis [4]. For instance, fusion of tools like geographic information systems (GIS) with Analytic Hierarchy Process (AHP) have been effectively applied to assess the area's best suitable for crop types such as cereal in a region; namely India's Haryana state [5]. By using such advanced techniques, the decision-makers can make educated decisions, leading to boosting agricultural productivity and effectively addressing food security challenges. Evaluating land suitability for agriculture in Mosul is more important because of the need to address urban food production and sustainably use the soil [6]. Water quality in the Tigris River is influenced by a complex interplay between phytoplankton, physical-chemical variables and land use [7] indicating to include soil assessment at stage. Furthermore, in an urban setting for example Bojnourd-Iran where soil pollution of heavy metal (like Antimony) could be evaluated that shows the importance of assessing tissue to maintain sustainable agriculture [8]. Soil health indicators such as soil microbial biomass and enzyme activity have been used to assist the assessment of agricultural land quality [9]. The research by Ahmed et al. studied dynamics of soil salinity and sodicity in northeastern Egypt by remote sensing [10]. Yaqi et al. investigated the effects of fertigation and carboxymethyl cellulose application on soil available nutrients, water-use efficiency (WUE) as well maize yield in salt-affected soils [11]. Dawei et al. studied the vacuolar molybdate transporter OsMOT1;2 and its role in regulating Mo remobilization from rice [12]. Additionally, Marwa et al. evaluated soil tolerance limits of two soil orders in Sulaimani City [13]. These studies help to unveil the soil salinity management, nutrient availability in walls of different crop species may improve Mo-transport mechanism and about bacterial tolerance towards heavy metals which is important for sustainable agricultural activities along with bio-diversity conservation. In the accompanying study by Oscar Andreu-Sanchez et al. focused on the evaluation of paddy field soils from Albufera Natural Park by an ecotoxicological battery test [14]. In contrast, Jan E. Groenenberg and his team studied the suitability of a single dilute (0.43 M) nitric acid extraction for determining geochemically reactive elements in soil [15]. Additionally, these studies underscore the relevance of a soil quality and reactivity assessment approach in agricultural set-ups like paddy fields for understanding any probable ecotoxicological risks as well as behavior associated with reactive elements present in the soils. These studies have led to several findings and therefore an increase in our understanding of soil health, as well

environmental impact assessments within agricultural landscapes. This study aims to evaluate the fertility and cultivation constraints in soils of Mosul according to their physicochemical properties. It is also to evaluate the rotation systematic practicability of Mosul Soil for different crop cultivation based on data and available advice about land use. Second, the purpose also compiles producing soil and land suitability maps in agriculture for Mosul to designate the best locations to grow varieties of crops by analyzing GIS models based on some relevant agricultural factors. Through the conjunctive use of soil analysis, land suitability classification and GIS mapping a formidable strategy is utilized to determine agricultural potential on various areas over Mosul which in turn helps contribute data for efficient land use planning mainly with respect crop selection while promoting sustainable agriculture.

1. Materials and Methods
1.1. Soil Sampling

Soil samples were collected from different places, Mosul (Al-Shura district and Al-Zahra), an experiment was also conducted in barracks collective fields on the land of Mr. Muhannad Modher Saadoon to grow almond seedlings with transgenic. Data analysis: Chemical analyses for the concentration of heaviest elements such as Ti, V Cr Mn Ni Cu Zn Ga AsBr Rb Sr Zr Nb Mo Cd Sb CePb Th. Soil investigations were also carried out using XRD, MED-XRF for the analysis of soil sample along with UCS (Unconfined Compression Strength), pH and Soil Texture Analyzer to determine Phyto-chemical properties. The work was done by analyzing the presence of heavy metals and other elements in soil—elements that are essential to understanding the agricultural value as well as risks related to possible contamination or whether geographic areas may potentially not be suitable for farming. We collected the soil from four areas, we took 6 cylinders at a time (500g / cylinder), so in total it was about 24 Cylinders. Soil samples from Mosul city were analyzed for different parameters associated with their agricultural quality. Several physicochemical properties, heavy elements content and contamination factors were also analyzed from the collected samples.

1.2. Soil Investigation Methods
1.2.1. X-Ray Diffraction (XRD) Analysis

Soil samples from Mosul were analyzed using the ADX-2500 XRD (Angstrom company, USA) to evaluate mineral composition for agriculture suitability. Analysis involves obtaining a representative soil sample, grinding it into a fine powder, and packing it for analysis. X-rays are generated using an X-ray tube, typically with copper (Cu) as the target material, producing Cu Kα radiation with a wavelength of 1.5418 Å, ideal for soil mineral analysis. These X-rays are sent into the powdered sample, and it diffracts in some specific angles by Bragg's Law revealing crystalline phases present inside the soil sample. The resulting diffraction pattern (with peaks at specific 2θ positions) is then quantified to assess the soil mineral composition based on d-spacing

values and such standards compiled in reference databases. This method will help to better identify soil minerals under XRD analysis.

1.2.2. X-Ray Fluorescence (XRF) Analysis

In MED-XRF analysis (EX-7555 Multi-Energy X-Ray Security Inspection Equipment, ESCAN company, China), for example of soil samples, a few grams of representative soil are ground to <75 μm particle size level in order that the matrix be homogeneous. To generate X-rays, electrons are accelerated towards a metal target (usually rhodium or tungsten) in an X-ray tube, which produces a spectrum of x-rays that include characteristic lines for the element used as the target. This fluorescence spectrometer is equipped to be used in analysis of major elements and trace elements if soils and it has capability for employing characteristic X-ray line by target element, which typically has wavelength that range between 0.5 -2.5 Å. The irradiated soil sample gives rise to element-specific fluorescence X-rays that are detected, energy and intensity measured for elemental identification and quantification.

1.2.3. pH Measurement

pH measurements in Mosul, Iraq, utilized the Hach Portable pH Meter (Serial Number: PM-2024) from Hach Company, USA, for soil analysis. Soil pH was estimated using air-dried and ground soil samples resulting in a (1:2.5) relation of soil to water solution suspension, agitation for 10 min, rest for another 15 min followed by measurement of the supernatant with calibrated pH meter Spectrophotometric methods (STISM and MTISM) with pH -sensitive dyes Materials Useful indicators MR, BV, BB, MTB. Soil pH is one measure of hydrogen ion concentration in the suspension, it plays an important role for plant growth, the optimum range: 6.0-7.5. The pH of the soil, which ranges between 0 through to 14 shows whether a soil is acidic or alkaline and this can be influenced by things like natural mineral content in coexistence with humus.
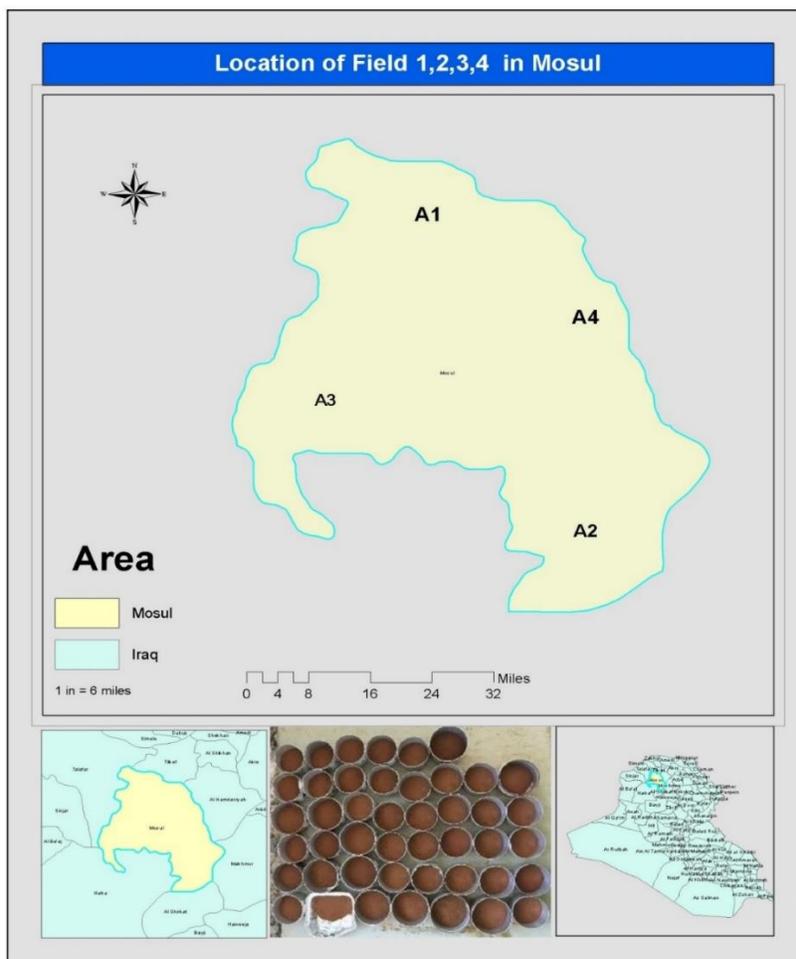
Figure 1. Location of Field 1 and Field 2 in Mosul, where the soil samples were collected.

1.2.4. Soil Texture Analysis

To prepare a soil sample for stokes law analysis, air-dry the soil followed by lightly crushing to get rid of large aggregates and debris. Then sieved the sample for fine earth fraction. Put a 30 – 50 g of sieved soil + dispersing agent (sodium hexametaphosphate) in water to completely disperse for at least five minutes. Add water to the dispersed sample and transfer it into a sedimentation cylinder, measure on intervals hydrometer readings for sand, silt and clay percentages. So, to calculate these percentages with the help of Stokes' Law and corrections then further classify into soil textures which can be done under a suitable system like USDA or International System. Knowledge of soil texture is essential for sound soil management practices like irrigation, fertilization and choice of crops. One of the uses of such parameter is in soil texture analysis, that used for calculating settling velocity value in Stokes' Law. The law is as follows:

$$v = \frac{2(\rho p - \rho f))}{9 \quad \eta} \, gR2$$

➢ v is the settling velocity of the particle (m/s)
➢ ρp is the density of the particle (kg/m³)
➢ ρf is the density of the fluid medium (kg/m³)
➢ η is the dynamic viscosity of the fluid medium (Pa·s or kg/(m·s))
➢ g is the acceleration due to gravity (m/s²)
➢ R is the radius of the particle (m)

A variation of Stokes' Law in Soil Texture Analysis; Sand, Silt, and Clay percentages can be found as the settling velocity in water. The entire process includes sizing and preparation of the soil sample, separation with dispersing agent in water into suspension (one phase), transfer to sedimentation cylinder for hydrometer reading recording… applying Stokes' Law looks at particle percentages. Several systems, like the USDA soil system or International System of Soil Classification are used to classify a given soil texture. This approach enables soil scientists to estimate precise percentages of the fine, coarse and medium fragments in each soil which helps them make decisions regarding managing soils, executing irrigation methods or selecting crops.

2. Result

2.1. X-Ray Diffraction (XRD) Analysis

Encouraging results are obtained from X-ray diffraction (XRD) analysis of soil samples collected in Mosul area, which have shown wide variation in the mineralogical composition of these soils. The results indicate that kaolinite, smectite, illite and chlorite are the dominant clay minerals detected in all three types of soils. It comprises 97.74 % of the sample A1 from north Mosul to only 8.45% in sample A4 from east Mosul Table (2). Among the different samples, smectite is virtually either the second or first to kaolinite in all cases except for A1 on which it occurs but at a much lower level. The content of illite varies from 1.26% in A1 to 3.52% in A3. Chlorite also has a relatively high content in sample A4 which varies from 2.99 to 5.13%. The ratio smectite/illite varies from 1.03 in A1 to 1.78 in A4 and indicates more weathered soils in the eastern parts of the study area as presented in table (1). Cation Exchange Capacity (CEC) of the soil differs from 19 to 52 cmol+kg-1. Soils in the northern and western part of the study area have higher CEC values, showing good fertility while soils in the eastern side shows poor to moderate soil (low to medium) fertility based on lower CEC. The smectite content had a positive correlation with CEC and opposed somewhat for the kaolinite contents, showing that its higher values of smectite present soils do reflect in high fertility. The results have important implications for the sustainable management and conservation of soil resources in Mosul soils under climate change and impending water shortages.

Table 1. X-Ray Diffraction (XRD) Analysis of Soil Samples from the Mosul Area.

Sample Code	Location	Kaolinite $2\theta=12.3$	Smectite $2\theta=5.4$	Illite $2\theta=8.8$	Chlorite $2\theta=12.3$ (Heat550)	Smectite/Illite $2\theta=13.14$	CEC[*] (Cmol+kg-1)
A1	North of Mosul	97.74	0.29	1.26	0.43	0.29	19
A2	South of Mosul	87.59	0.59	5.13	6.10	0.59	22
A3	West of Mosul	70.85	11.47	16.62	0.63	0.42	30
A4	East of Mosul	8.45	51.31	35.22	2.99	2.03	52

The X-ray diffraction (XRD) pattern provided for soil sample in figure (2-A1, A2) displays two curves representing diffracted X-ray intensity against the 2-theta angle. The blue curve represents the soil sample after 14 hours, while the red curve represents the same sample after 28 hours. Both curves exhibit distinct peaks at specific 2-theta values, indicating the presence of crystalline components within the soil, with prominent peaks around 20 and 27 degrees 2-theta, typical of clay minerals like montmorillonite or kaolinite. The sharp peaks suggest a crystalline mineral presence, and comparing the two curves allows for studying changes in the crystalline structure over time or under different conditions, showing stable mineral phases over the experiment's duration. This XRD analysis is essential for identifying and quantifying the mineralogical composition of soil samples. The X-ray diffraction (XRD) pattern for soil fractions smaller than 0.002 mm in figure (2-A3, A4) reveals key insights. The sharp peak at around 6 degrees 2-theta, present in both the red and blue plots, signifies a strong crystalline component. Additionally, various smaller peaks and fluctuations between 15 and 30 degrees 2-theta suggest diverse crystalline phases or particle sizes within the soil sample. This XRD analysis aids in identifying the mineralogical composition of the soil, offering valuable information on its properties and potential applications in agricultural or environmental contexts. The technique's ability to detect different crystalline components and variations in particle sizes contributes to a comprehensive understanding of the soil's characteristics and behavior, essential for informed decision-making in various fields [18].

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[*] Cation Exchange Capacity (CEC) is a critical soil property that indicates its ability to hold and exchange essential cations, influencing nutrient availability and soil fertility in agricultural assessments, particularly in Mosul.
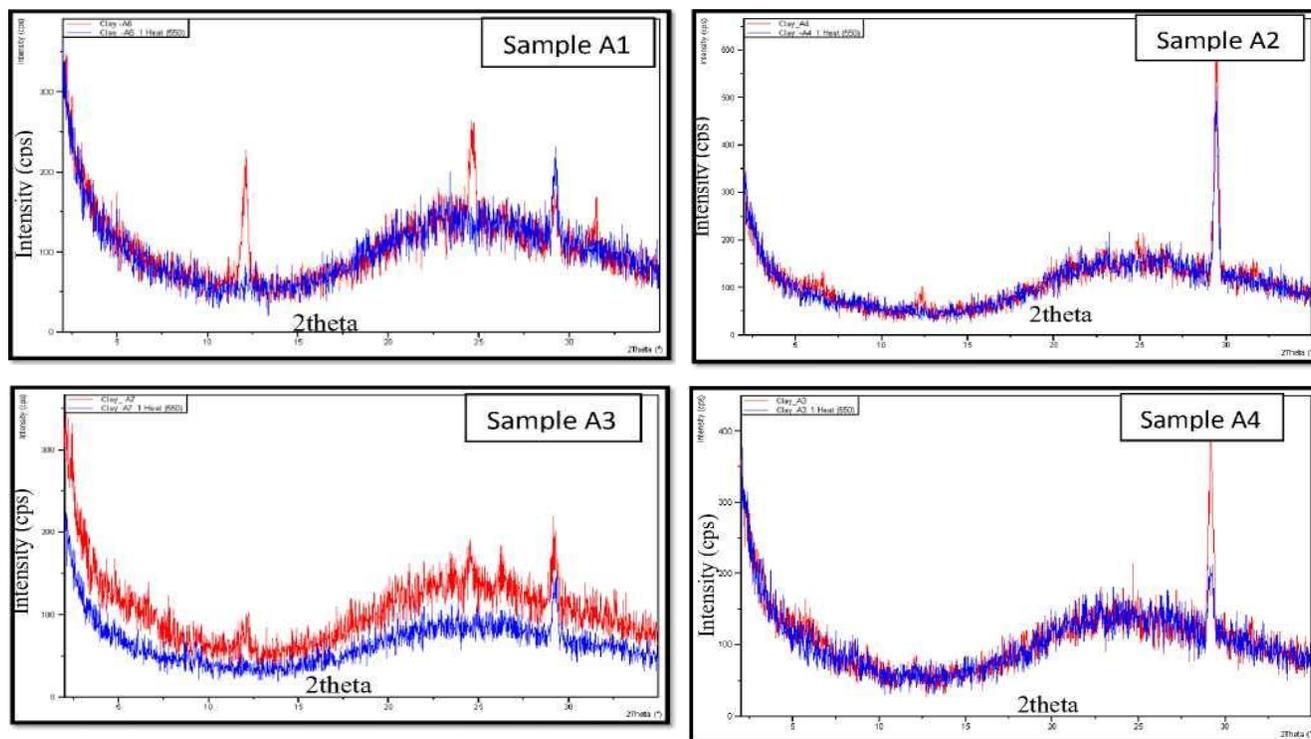
Figure (2). XRD patterns of soil fractions (<0.002 mm) of sample A1,2,3,4.

2.2. Soil Texture Analysis

As mentioned previously, area (1) has the most variable soil texture, and this makes a large impact on what types of soils are formed there and how they can be used. Soils with moderate texture, such as Sample 1 silt loam soils do hold the water well and have good nutrient holding capacities which make them ideal for agriculture. Sample 2 shows a sandy loam soil, being well- drained and easy to till with balanced composition. Samples dominated by sand (i.e. Sample 3 and Samples 4–6) could be predicted to have low water-holding capacity but high infiltration rates. The pH levels for all these samples are mild acidic which is commonly expected in cultivated soils. The Hydrologic Soil Groups vary, indicating differences in infiltration rates and runoff potential, with sandier soils having higher infiltration rates.

Soil texture data for the samples in area (A2) reveals a mix of textures. Sample 7 is classified as Loam despite a high sand content of 98%, likely due to well-aggregated particles. The pH is neutral, and it falls under Hydrologic Soil Group B, indicating moderate infiltration. Samples 8-12 are predominantly sandy, with sand content ranging from 95% to 98%. The pH ranges from 6.9 to 7.2, showing neutral to slightly alkaline conditions. These samples belong to Hydrologic Soil Group A, suggesting high infiltration rates. Overall, the area A2 soils are sandy, with one loam sample. They exhibit good drainage but low water and nutrient retention. The pH is neutral to slightly

alkaline, and most samples are in Hydrologic Soil Group A, indicating high infiltration rates.

The soil texture data for the samples in area (A3) varies from loam to sand and loamy sand. Sample 13 exhibits a loam texture with balanced sand (81%), silt (14%), and clay (5%), ideal for agriculture due to good water-holding capacity and nutrient retention. Sample 14 is predominantly sandy (91.22% sand), with low silt and clay content, categorized as sand. Sample 15 also shows a loam texture but with higher silt content (20%), maintaining good water retention properties. Samples 16-18 range from sand to loamy sand, with varying sand, silt, and clay compositions, resulting in a loamy sand texture. The pH levels across the samples indicate slightly acidic conditions, ranging from 5.1 to 5.7. The Hydrologic Soil Groups vary between A and B, reflecting different infiltration rates and runoff potentials.

The soil texture data for the samples in area (A4) specially samples 19-20 exhibit a Silt Loam texture with 44.8-49.5% sand, 32.47-52% silt, and 5.7-15.3% clay, providing good water-holding capacity and nutrient retention suitable for agriculture. Samples 21-22 display a Sandy Clay Loam texture with 51.6-66% sand, 18.8-24.4% silt, and 21.2-24% clay, offering moderate water-holding capacity and nutrient retention, also suitable for agriculture. Sample 23 showcases a Loam texture with 48.42% sand, 39.5% silt, and 12.3% clay, providing a balanced composition ideal for agriculture. Sample 24 presents a Sandy Loam texture with 60.3% sand, 27.5% silt, and 12.2% clay, offering characteristics like the loam sample, suitable for agricultural purposes.

Table 2. Soil Texture Analysis Results for Sample Locations in the Mosul Area.

Sample Code	NO.	Easting (m)	Northing(m)	%sand	%silt	%clay	Soil texture	PH	Hydrologic Soil Group
	1	577708	3627338	36	62	2.0	Silt Loam	6.6	C
	2	577425	3638033	54.5	44	1.5	Sandy Loam	6.6	B
A1	3	583001	3655898	97.9	1	1.1	Sand	6.5	A
	4	594831	3668925	72.5	25.8	1.7	Loamy Sand	6.4	A
	5	598131	3672208	98.68	1	0.32	Sand	6.4	A
	6	600280	3679999	96.75	2.25	1	Sand	6.1	A
	7	594253	3685677	98	1	1	Loam	7.1	B
	8	592216	3693059	97	2	1	Sand	7.1	A
	9	587878	3690358	95	2.8	2.2	Sand	7.2	A
A2	10	607447	3675009	97	2	1	Sand	7.2	A
	11	605058	3678716	97.2	1.5	1.3	Sand	7	A
	12	599412	3677184	98	1	1	Sand	6.9	A

	13	586908	3673578	81	14	5	Loam	5.5	B
	14	592562	3664489	91.22	4.04	4.74	Sand	5.4	A
	15	603446	3656059	77.76	20	2.24	Loam	5.7	B
A3	16	601536	3640867	97.4	1.2	1.4	Sand	5.6	A
	17	615492	3637193	81	14.3	4.7	Loamy Sand	5.1	A
	18	645063	3632573	80	14.6	5.4	Loamy Sand	5.3	A
	19	636406	3605904	4448	49.5	5.7	Silt Loam	6.3	C
	20	551394	3639925	3247	52	15.3	Silt Loam	6.3	C
	21	547778	3656983	66	18.8	21.2	sandy clay loam	6.3	C
	22	557171	3661481	51.6	24.4	24	Sandy Clay Loam	6.4	C
A4	23	565532	3668413	4842	39.5	112.3	Loam	6.5	B
	24	573838	3686531	60.3	27.5	12.2	Sandy Loam	6.5	B

2.3. Elemental Concentrations in Soils (MED-XRF)

The comparison of Certified Values and MED-XRF Results demonstrates the reliability of the MED-XRF technique, with good agreement observed for most elements. Elements like Ti, Mn, Ni, Cu, Zn, Ga, As, Br, Rb, Sr, Zr, and Pb fall within the certified value ranges, showcasing the accuracy of the results. Despite that V, Cr and Ce are slightly lower with MED-XRF, Limits of Detection (LODs) as compared to the HJ 780-2015 standard. This demonstrates that the MED-XRF is more sensitive and can detect much lower element concentrations needed in environmental monitoring. These findings underscore its enhanced analytical application.

The detection results of the MED-XRF method for various elements meet HJ 780-2015 standards, most elements are rated as "1", which is in line with standard requirements. V, Cr and Ce were rated to show decreased performance relative to reference standards with a "-1" rating. As well, no similar standard in HJ 780-2015 for Nb In comparison to environmental quality standards, elements of V, Cr, Ni, Cu, Zn and Cd are limited all by the MED-XRF outcomes (which fall in it) tells that soil and sediment sample obviously did not exceed regulatory limitations. This indicates the potential of MED-XRF for precise evaluation of heavy metal content in environmental samples and meeting oftentimes stringent criteria (Table 3).

Table 3. Evaluation of Elemental Concentrations in Soils and Sediments by MED-XRF and Comparison to HJ 780-2015 Standards.

Elements	Certified Value/(mg/kg)	Average/(mg/kg)	Std./(mg/kg)	MED-XRF LOD./(mg/kg)	HJ 780-2015 LOD./(mg/kg)[**]	Evaluation Results	The Max. Relevant Environmental Quality/(mg/kg)	NSEM Network Monitor-ing
Ti	1370 ± 120	1437	6.6	21	50	1	/	Yes
V	19 ± 3	15.8	2.5	7.7	4	−1	165	Yes
Cr	10.7 ± 1.7	8.45	1.6	5	3	−1	80	Yes
Mn	218 ± 31	238	0.9	2.8	10	1	/	Yes
Ni	3.7 ± 1	3.7	0.18	0.6	1.5	1	40	Yes
Cu	11 ± 2	9.6	0.27	0.8	1.2	1	35	Yes
Zn	18 ± 2	20.1	0.12	0.4	2	1	150	Yes
Ga	11.1 ± 0.9	10.1	0.23	0.7	2	1	/	Yes
As	2 ± 0.2	1.68	0.12	0.4	2	1	20	Yes
Br	0.5	0.56	0.05	0.2	1	1	/	Yes
Rb	70 ± 6	67.4	0.07	0.3	2	1	/	Yes
Sr	87 ± 4	84.6	0.11	0.4	2	1	/	Yes
Zr	187 ± 14	176	0.12	0.4	2	1	/	Yes
Nb	9 ± 1.1	9.2	0.04	0.1	2	1	/	No
Mo	0.44	0.19	0.03	0.1	/	1	/	Yes
Cd	0.045	0.05	0.01	0.04	/	1	0.3	Yes
Sb	0.19 ± 0.06	0.18	0.03	0.1	/	1	/	Yes
Ce	42 ± 4	32.84	7.26	22.8	24.1	1	/	Yes
Pb	13.5 ± 2.3	13.7	0.11	0.4	2	1	50	Yes

[**] The values measured according to HJ 780-2015 standards are not derived from the same MED-XRF device. While the comparison between certified values and MED-XRF results demonstrates the reliability of the MED-XRF technique, with good agreement observed for most elements, a different device is used for determining measured values in accordance with the HJ 780-2015 standard, which often relies on other techniques such as wavelength dispersive X-ray fluorescence (WD-XRF) analysis. Elements like Ti, Mn, Ni, Cu, Zn, Ga, As, Br, Rb, Sr, Zr, and Pb fall within the certified value ranges, showcasing the accuracy of the results. Although V, Cr, and Ce show lower performance with MED-XRF, the Limits of Detection (LODs) in comparison to the HJ 780-2015 standard indicate that MED-XRF is more sensitive and can detect much lower element concentrations needed in environmental monitoring. This increasingly supports the application of MED-XRF for precise evaluation of heavy metal content in environmental samples and compliance with stringent standards.

| *Th* | 5.4 ± 0.6 | 4.7 | 0.05 | 0.2 | 2.1 | 1 | / | Yes |

2.4. Relative Errors of Elements

The Relative Errors of some heavy metal elements measured by the MED-XRF technique in different soil and sediment samples are obviously quite high, Cr with errors ranging from (1.1-33) %, Cu from (0.5 to19) %. Generally, elements like (Cr, Ni and Cd) show higher relative errors than others such as (Zn, As associated with Pb). Relative errors are reproducible between sample types (low for GSS vs high for GSD), but absolute error rates in terms of nucleotides differ. Errors can arise from the concentrations of elemental constituents, sample matrices and potential interferences. Despite the differences, the percent relative errors observed fell within acceptable bound by HJ/T 166-2004 standard for XRF analysis (table 4), suggesting that MED-XRF is a reliable and accurate technique to analyze heavy metals in soil/sediment samples.

The equation to calculate the Relative Error (RE) of elements can be expressed as follows [19]:

Relative Error (RE)} = Measured Value}-{True Value}*True Value \times 100%]

Where:

- **Measured Value** is the value obtained from the MED-XRF results.

- **True Value** is the certified or accepted value of the element as per standard reference.

This equation allows the assessment of how significant the error is in relation to the true value, expressed as a percentage.

Table 4. Relative Errors of Elements Analyzed by MED-XRF.

Relative Error/(%)	Cr	Ni	Cu	Zn	As	Cd	Pb
GSS-1a	4.8	9.0	0.5	3.5	8.1	3.7	3.8
GSS-2a	30	7.0	6.4	2.7	10	16	21
GSS-8a	4.5	2.9	2.4	7.3	2.6	3.5	8.0
GSS-24	4.0	8.8	16	7.4	3.6	21	2.3
GSS-34	3.6	4.9	6.8	2.0	2.1	31	8.6
GSS-39	14	8.9	8.2	3.0	12	15	9.5
GSS-40	3.6	8.5	5.2	1.4	3.5	12	8.0
GSS-50	11	6.9	8.6	0.3	20	3.7	0.4
GSS-60	17	9.0	6.2	2.8	3.7	1.4	4.9
GSS-63	6.6	4.0	3.6	0.3	8.3	11	2.2

GSD-19	2.4	6.6	11	3.3	53	15	3.6
GSD-26	32	3.4	12	0.2	4.6	1.9	3.8
GSD-27	1.1	1.1	3.7	3.6	9.7	7.3	4.0
GSD-29	2.7	1.9	3.7	0.5	75	11	30
GSD-30	12	6.5	4.8	3.0	9.1	0.3	6.5
GSD-32	33	2.7	5.5	1.1	7.4	2.1	6.7
GSD-13	8.0	7.8	19	8.6	26	10	0.0

2.5. Precision Evaluation of MED-XRF

The relative percentage deviation in elemental concentrations of soil-sediment standard reference materials (GSS-1a and GSS-2a) were calculated also by using portable X-ray fluorescence spectrometry analysis. These analyses covered Ti, V, Cr, Mn and Ni to some extent Cu Zn among others thus indicating the wide range of elements considered. These % RDs serve as important performance indicators of the precision and reproducibility produced by pXRF analysis about environmental samples, demonstrating that this technique is reliable and useful for determining elemental concentrations in soil/sediment samples. In addition, we demonstrated the value of these deviations in informing detection performance to be expected for environmental applications of pXRF analysis. Relative percentages of elemental concentrations were determined from analysis using portable X-ray fluorescence (pXRF) spectrometry on soil and sediment standard reference materials GSS-1a, and 2 a This comprised Ti, V, Cr, Mn, Ni to Zn among others showing that a very wide variety of elements were investigated. These relative percent deviations serve as an important check on the precision and repeatability of pXRF analysis under environmental sample conditions, thus verifying the robustness of this tool for quantifying elemental composition in soil and sediment samples. The importance of assessing these deviations as an integral part in the performance evaluation and repeat-ability measures for pXRF analysis specific to environmental applications was also reflected appropriately by this study. The varying precision observed in pXRF analysis results for different elements, such as Cr, Ni, Cu showing acceptable precision, while Ti, V, Mn displaying higher deviations, can be attributed to several factors. Sample heterogeneity, instrument sensitivity, and potential interferences during analysis contribute to this discrepancy. Techniques like multiple linear regression analysis can help correct matrix effects and improve precision, especially for elements like Co, Zn, Mo, Ta, Tl, Pb, Cd, and Sn [5]. Understanding and addressing these factors are crucial for enhancing the accuracy and reliability of environmental analyses using pXRF, highlighting the intricacies involved in elemental analysis in environmental studies.

The precision evaluation of the MED-XRF technique can be assessed using the following equation, commonly used to quantify the precision of measurements:

Relative Standard Deviation (RSD) ={sigma}{bar{x}} \times 100\%

Where:

- (sigma) = Standard deviation of the measured values.
- (bar{x}) = Mean (average) of the measured values.

This equation calculates the Relative Standard Deviation (RSD), which expresses the precision of the measurements as a percentage of the mean value. A lower RSD indicates higher precision in the measurement results obtained from MED-XRF.

In addition, the standard deviation (sigma) can be calculated using the formula:

sigma = sqrt{{sum_{i=1}^{n} (x_i - bar{x})^2}{n - 1}}

Where:

- (x_i) = Each individual measured value.
- (n) = Total number of measurements.

These equations provide a comprehensive approach to evaluate the precision of the MED-XRF technique in soil composition analysis.

Table 5. Precision Evaluation of MED-XRF Analysis for Soil and Sediment Samples.

Relative	Ti	V	Cr	Mn	Ni	Cu	Zn	Ga	As	Br	Rb	Sr	Zr	Nb	Mo	Cd	Sb	Ce	Pb	Th
GSS-1a	0.3	21	11	7.2	7.7	1.3	3.5	6.8	7.3	20	5.4	2.6	1.2	7.5	7.2	3.6	2.4	21.5	3.4	7.8
GSS-2a	0.3	10	11	3.6	7.2	5.9	2.7	3.3	9.4	3.9	2.4	3.2	8.3	7	10	0.4	0.9	13.9	18	8.6
GSS-8a	0.6	16	7.7	1.9	2.4	4.8	6.9	3.7	2.3	3.7	3.3	3.1	4.6	12.5	3.6	19.9	1.2	17.3	8.8	6.1
GSS-24	0.3	3.5	5.6	0.1	8.2	15.1	7.7	10.3	4.2	0	2.8	9.9	4.4	1.5	3	25.6	1.1	14.7	2.9	4.9
GSS-34	0.3	0	6.9	4.6	6.1	4.4	2	3.1	2.2	7.6	1.4	0.2	5.1	1.7	2	22.2	1.1	20.2	8.7	14
GSS-39	0.2	11	13	7.6	10.1	8.9	3.1	6.3	10.8	0.4	2.8	4.4	2.7	8.8	8.5	11.5	1.1	18.8	9.9	2.1
GSS-40	0.4	6.5	7.4	5.1	7.8	5.7	1.7	5.2	3	1.2	2.2	2.2	2.3	6.6	6.2	8.4	1.2	11.3	8.3	5.7
GSS-50	0.3	18.7	9.3	0.6	6.7	6	0.3	6.8	11.7	1.9	3.2	2.8	2.6	0.8	0.4	7	0.4	22.4	0.1	12
GSS-60	0.2	18.8	15.7	2.3	6	7.6	2.4	2.3	3	9.2	0.6	0.4	10	5	4.4	10.2	1.8	16.5	5.4	13
GSS-63	0.1	1.7	6	1.3	2.4	2.7	0.3	2.5	9.8	12.9	0.8	0.3	4	2.8	7.9	6.1	1.2	18.3	2.1	3
GSD-19	0.3	4.5	2.1	2.2	7.2	10.3	3.7	8	6.4	2.2	0.3	1.8	15	2.6	7.1	12.5	0.2	17.3	3.8	7.9
GSD-26	2.1	4	16.2	0.3	1.5	9.1	1.3	2.1	5.4	22.1	1.8	2.5	5.7	0.4	4.1	19.2	2.5	19.7	3.4	9.3
GSD-27	0.3	9.1	4.1	2	5.4	3.5	3.8	8.8	8.9	13.7	2	2.5	1.1	4.2	1.3	3.8	1	17.8	4.3	17
GSD-29	0.1	5	2.9	11.9	1.9	4.1	0.1	0.3	7.1	7.2	6.6	3	2	1.7	1.7	16.1	0.2	22.6	19	24
GSD-30	0.4	5.7	13.3	3.2	5.6	2.7	2.8	6.8	9.5	3.6	1.8	4.7	2.9	1.3	6.3	1	1.9	22.3	6.6	4.2
GSD-32	2.6	2.6	13.2	4.2	2	4.3	0	5.3	7.9	8.1	2.7	10.8	4.9	2.6	3.9	1.9	1.2	14.6	7.2	6.4
Acceptable?	—	—	Yes	—	Yes	Yes	Yes	—	Yes	—	—	—	—	—	—	Yes	Yes	—	Yes	—

Our data thus imply that portable X-ray fluorescence (pXRF) analysis can yield reliable results for selected elements in soil and sediment samples, but additional calibration might be required if those more affected by relative percentage deviation. Consequently,

it is imperative that we conduct more comprehensive studies to give a clearer picture on the full capacity (as well as the constraints) of pXRF analysis for elemental determination in difficult environmental matrices such as soils and sediments. Areas such as the preparation of the sample with respect to water content and excitation times can have significant impacts on both precisions, due to differing amounts of analyte reaching the detector at different injection intervals, and accuracy in readings; thus, it is important –vital– that these parameters are optimized for robust XRF. Consequently, continued improvement and calibration are required to improve the meaningfulness of pXRF analysis in complex environmental backgrounds.

3. Discussion

X-ray diffraction (XRD) analysis of soil samples collected from various locations in Mosul has shown the presence of different clay minerals, such as kaolinite, smectite, illite, and chlorite [10]. These clay minerals significantly influence the characteristics of the soil, including its fertility and ability to retain water. The study found that the amount of kaolinite varied considerably among the soil samples, suggesting that Mosul has a diverse range of soil compositions. This diversity in soil composition can have implications for agricultural suitability and the way in which the soil is managed for farming purposes. The analysis also identified smectite, a clay mineral known to improve soil fertility. This is because smectite has a positive correlation with the soil's Cation Exchange Capacity (CEC), which is a measure of the soil's ability to hold and exchange nutrients. Consequently, areas with a higher content of smectite in the soil may be more conducive to agricultural activities [11]. In addition, the study by Dawei, et al. 2022 [12] also underlined inadequate at present approaches. They presented changes in soil mineral composition that can be observed with the change of time or under certain factors, while aspects of XRD patterns may shift, which also proves that soil management strategies should be changed as well. XRD allowed Dawei, et al. 2022 [12] to demonstrate that Mosul soils include various types of clay minerals, such as kaolinite, smectite, illite, and chlorite, which change soil properties, for example, its fertility or water-retention. The presence of kaolinite varied strongly between samples, showing the diversity of soil composition in various areas of Mosul that may affect their suitability for agriculture and farming. Another clay mineral, smectite is associated with increased soil fertility as it positively correlates Cation Exchange Capacity (CEC), indicating that the areas where there are higher proportions of this specific type of clay may offer suitable conditions for agriculture. The XRD pattern analysis also indicated that soil mineral composition can change temporally or under different environmental conditions, which implied the plasticity of some properties.

Soil texture analysis in Mosul city area as reported in the research of Yaqoob et al. [6]. The text pointed at a wide range of soil types from loam to sand /loamy sand [6] reflecting different soil classifications which made this region suitable for several agricultural practices. In particular, the balance of sand and silt to clay was most optimal in sample 13 which has a loam texture. This equilibrium leads to formation of a soil that has very good water retention as well nutrient excitation powers, making it highly conducive for agriculture. In rural agricultural regions, soil properties like depth and profile are key elements in the risk assessment for water erosion [10], which demonstrates that it will help to consider these factors when planning future agriculture or conservation. This level of intensive analysis is important for the sustainable management and efficient use of soil in this region. Alternatively, Sample 14 is purely sandy soil which holds far less water and nutrients making this take up more irrigation & fertilizer. This texture (loamy sand) as indicated in samples 16 to18 provides moderately good water retention capacity and nutrient availability; thus, can be used for growing crops that need well-drained soils. These samples reveal moderately acidic pH levels that affect nutrient availability from the soil to plants, requiring amendment for crop growth. MED-XRF analytical technique showed close agreement to certified values for elemental compositions of elements including Ti, Mn and Zn ([14], Table 5). The highest sensitivity of MED-XRF can detect even low concentrations in some elements like V (34), Cr (24) and Ce which are slightly lower than standards [15] The MED-XRF analysis results matched with the environmental quality standards regarding to Ni, Cu and As elements suggesting that for these metals there is no toxicological risk in the tested soil samples [16]. Although some elements did not conform to the standard, in general MED-XRF was considered appropriate for heavy metal analysis of environmental samples with respect to that meeting legal regulation as regards environment quality [17].

The application of the MED-XRF technique in the analysis of soil and sediment samples reveals a notable variability in relative errors across different elements and sample types. Of particular interest is the case of Chromium (Cr), which exhibits a wide range of relative errors spanning from 1.1 to 33. This substantial variation underscores the potential for significant differences in measurement precision among different elements and sample matrices. In contrast, elements such as Zinc (Zn), Arsenic (As), and Lead (Pb) demonstrate comparatively lower relative errors. This observation suggests that the MED-XRF technique offers enhanced consistency and reliability in the quantification of these elements, particularly when juxtaposed with the more variable results obtained for Chromium (Cr), Nickel (Ni), and Cadmium (Cd). Furthermore, an examination of the relative errors within specific sample types reveals an intriguing pattern. Geological Survey Soil (GSS) samples generally exhibit lower relative errors compared to their Geological Survey Sediment (GSD) counterparts. This consistent trend across sample

types serves to illuminate the significant influence that sample matrix composition and potential interferences may exert on measurement accuracy in MED-XRF analyses. These findings underscore the importance of considering element-specific and matrix-dependent factors when interpreting MED-XRF results and highlight the need for careful calibration and validation procedures to optimize the technique's performance across diverse geochemical samples.

The MED-XRF method would appear to be quite reliable and accurate in determining the heavy metals level in soils and sediments, although greatly depending on variation between relative errors. It is worth mentioning that most elements studied are within tolerance limits according to published standards, which supports the validation of this analytical methodology. A complete precision evaluation of the MED-XRF method for soil and sediment samples indicates its capabilities to accurately quantify elements like Titanium (Ti), Vanadium (V) or Chromium (Cr). This assessment provides meaningful information on the reproducibility of measurements for identical samples and one which is crucial in evaluation of method robustness. The most promising results were achieved for elements like Cr, Ni and Cu that showed good precision. This would indicate that the MED-XRF method is able to measure these elements consistently and accurately among a diverse range of samples with only slight differences in variation, lending confidence to the quality of data generated. However, it should be mentioned that Titanium (Ti), Vanadium (V) and Manganese (Mn) presented the highest deviations in its precision evaluation. This observation implies a potential for increased variability in measurements between tests of these elements. These differences might stem from intrinsic sample heterogeneity or alternatively are a result of the different sensitivities in detection for these elements within both techniques (MED-XRF). To overcome these limitations and to improve both the accuracy of MED-XRF method especially for major elements with high discrepancies using advanced statistical methods such multilinear regression analysis, is suggested. These analytical methods might help balance out the influence of confounding effects that can distort results, playing an important role in making these measurements more accurate and reliable overall. The present study reveals some limitations/handicaps of the MED-XRF technique for determination heavy metals in soil and sediment samples but, as per ongoing or advanced modifications (superior applications tools), might excessively enhance this process which could be proudly followed-up to wide-ranging on geochemical research issues.

4. Conclusion

The pedological profile of Mosul showcases a complex variety of soil compositions, featuring clay minerals such as kaolinite, smectite, illite, and chlorite, which significantly impact the soils' fertility and water retention capabilities, enhancing their suitability for diverse agricultural practices. Soil texture analysis indicates a

heterogeneous range from loam to sand, with loamy areas particularly advantageous due to their balanced water-holding capacity and nutrient retention, promoting sustainable crop production. Ongoing monitoring of heavy metals and other elements is essential for managing contamination risks and ensuring the sustainability of agricultural practices in the region. Advanced analytical techniques, such as X-ray diffraction (XRD) analysis, provide detailed insights into the mineral composition, while Geographic Information System (GIS)-based modeling enhances the visualization and understanding of soil properties. The integration of these techniques leads to the creation of detailed agricultural land suitability maps, aiding in informed land use planning and crop selection. In summary, a comprehensive approach that combines advanced analytical methods with continuous monitoring will be vital for maximizing the agricultural potential of Mosul's soil while preserving environmental integrity for future generations.

Findings

1) Area (A3) with loam to sandy loam soils, like Sample 13, is highly suitable for agriculture due to its good water-holding capacity and nutrient retention, making it ideal for growing a variety of crops.
2) Samples 19-20 in area (A4) showing a Silt Loam texture offer good water-holding capacity and nutrient retention, which are favorable conditions for agricultural activities.
3) The presence of loam textures, as seen in Sample 23 from area (A4), provides a balanced composition of sand, silt, and clay, making it an optimal choice for farming due to its excellent water and nutrient retention capabilities.

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