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An Analytical Study of Physicochemical Properties under Industrial Influences

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ABSTRACT

Agricultural soils in the coastal city of Zuwara, Libya, are under increasing pressure due to human activities and natural factors. This study aims to comprehensively assess soil quality by analyzing its physical and chemical properties, with a particular focus on salinity parameters (pH, electrical conductivity, total dissolved salts, and major ions) as indicators of environmental pollution. Nine composite soil samples (S1-S9) were collected and analyzed. The results revealed significant spatial variation: electrical conductivity (EC) values ranged from 190 to 1840 µS/cm, with sample S8 showing an abnormally high EC (1840 µS/cm) and total dissolved salts (TDS) (1177.6 mg/L), indicating severe localized salinization, possibly due to industrial waste or seawater intrusion. The concentrations of the major ions (Na^+, Cl^-, Ca^+, Mg^+, and SO_4^-) in S8 were significantly elevated and showed a strong correlation with each other, confirming the presence of an external source of pollution. The pH ranged from slightly acidic to slightly alkaline (6.96–7.98). The sodium uptake ratio (SAR) for sample S8 was 3.26, indicating a low risk of further sodium pollution. Potassium (K^+) deficiency was a critical issue, observed in 88.9% of the samples, severely limiting soil fertility. The study highlights two main problems: salinity pollution from a specific source and widespread potassium deficiency. Immediate action is recommended, including conducting an environmental study in the S8 area, implementing soil leaching techniques, planting salt-tolerant crops, developing potassium fertilization programs, and establishing a long-term monitoring system

الخلاصة

تهدف هذه الدراسة إلى تقييم جودة التربة الزراعية في مدينة زوارة الواقعة على الساحل الغربي الليبي , من خلال تحليل الخصائص الفيزيائية والكيميائية للتربة في اطار تزايد النشاط الصناعي بالمنطقة .تم جمع تسع عينات تربة من عمق 30-25 سم من مناطق غرب وجنوب وشرق المدينة خلال شهر فيربر 2025 اجري تحليل شامل للمعايير الأساسية لجودة التربة شمل الرقم الهيدروجيني(pH) ، والتوصيل الكهربائي (EC) ، والمواد الصلبة الذائبة الكلية (TDS) ، وتركيزات الأيونات الأساسية NH_4^+، NO_3^- ، SO_4^{2-} ، Cl^- ، Mg^{2+} ، Ca^{2+} ، K^+ ، Na^+ أظهرت النتائج تنوعاً واضحاً في قيم الرقم الهيدروجيني التي تراوحت بين 6.96-7.98، مما يشير إلى اوساط حمضية قليلة إلى قلوية معتدلة . سجلت قيم التوصيل الكهربائي تبايناً كبيراً من $190 - 1840\ \mu S/cm$ ، مع قيم استثنائية عالية في العينة S_8 $(1840\ \mu S/cm)$ التى تشيرالى مستويات عالية من الملوحة . تراوحت قيم المواد الصلبة الذائبة بين$-$ 121.60 $1177.60\ mg/L$ ، مع تركيزات مرتفعة للكالسيوم والكلوريد في معظم العينات .تشير النتائج إلى تأثير محتمل للأنشطة الصناعية المجاورة على جودة التربة، خاصة في المواقع التي أظهرت قيماً عالية للتوصيل الكهربائي والمواد الذائبة .توصي الدراسة بضرورة المراقبة المستمرة لجودة التربة ووضع استراتيجيات للحد من التلوث الصناعي لضمان استدامة الإنتاج الزراعي في المنطقة.

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Received: 20-08- 2025 - ***Accepted:*** 27-08-2025 - ***Published:*** 02-09-2025

Keywords. Soil quality 1; salinity, Zuwara 2; electrical conductivity (EC) 3; potassium deficiency 4; sodium uptake ratio (SAR) 5

الكلمات المفتاحية : جودة التربة، زوارة، التلوث الصناعي، الخصائص الفيزيائية والكيميائية، الرقم الهيدروجيني، التوصيل الكهربائي.

Introduction:

Agricultural soils in coastal areas are a vital resource for food security and the livelihoods of local populations. However, these ecosystems are particularly vulnerable to numerous anthropogenic and natural factors, including salinization, industrial pollution, and soil degradation (Sitia et al., 2021). In Libya, a country with an arid and semi-arid climate, land degradation is particularly severe. The city of Zuwara, located in northwestern Libya, is a prime example of a coastal zone where agricultural activities are facing increasing challenges related to soil quality (Ammari et al., 2021). Intensive industrial development, urbanization, and the potential impact of marine intrusion are placing complex pressures on local agricultural ecosystems, requiring urgent scientific assessment to develop sustainable management strategies Soil suitability is determined based on its physical, nutritional, and biological properties. Among soil indicators, salinity is one of the most important factors limiting agricultural productivity (FAO, 2019). Salinity is traditionally measured by parameters such as electrical conductivity (EC) and total dissolved solids (TDS), which directly reflect the concentration of dissolved salts in the soil solution (Richards, 1954). Additionally, the content of essential ions such as sodium (Na^+), chloride (Cl^-), calcium ($Ca_2{}^+$), magnesium ($Mg_2{}^+$), and sulfate ($SO_{42}{}^-$) provides a more detailed understanding of the sources and types of salinity, as well as associated risk terms such as alkalinity (sodium) (Sumner, 1993). Soil pH remains a key parameter affecting the availability of nutrients and toxic elements in the Zuwara region, in addition to natural processes such as evaporation and potential seawater intrusion (Werner et al., 2013), industrial activity significantly impacts soil quality. Industrial wastewater discharge can lead to the accumulation of salts, heavy metals, and other pollutants in the soil, altering its physical and chemical properties and posing risks to the ecosystem and human health (Rodriguez et al., 2022; Kumar and Sharma, 2020). Preliminary data from samples taken in the region indicate significant spatial variation in soil parameters, with one sample (S8) exhibiting exceptionally high EC and TDS values, suggesting severe localized pollution (Mind Map, 2025). This "spot" source of pollution requires careful investigation to pinpoint its origin and assess its potential impact in addition to the salinity problem, a serious fertility issue has been identified in the soils of Zuwarah: potassium (K^+) deficiency. Potassium is a vital nutrient that plays a key role in regulating osmotic pressure, activating enzymes, and enhancing plant resilience to abiotic stresses, including salinity and drought (Hassan Alzaman et al., 2018; Wang et al., 2013). The potassium deficiency observed in most of the studied samples directly limits yield potential and the crops' ability to withstand adverse environmental conditions (Zorb et al., 2014; Romhild and Kirkby, 2010). This dual problem—high salinity and low fertility—poses a serious threat to the sustainability of agriculture in the region. Therefore, a comprehensive assessment of soil quality in Zuwarah is clearly needed. Current research in Libya is often fragmented, and few studies focus on the relationship between industrial impacts and the agrochemical properties of soils in specific locations, such as Zuwarah. This study aims to fill this gap. Developing targeted strategies for reclaiming saline soils, improving fertilizer application systems, and reducing the negative impact of industrial activities on valuable agricultural land

Materials and Methods

Study Area and Sample Collection Zuwara is a coastal city in northwestern Libya. Nine composite soil samples (S1-S9) were collected from the top layer (25-30 cm) from various agricultural areas surrounding the city (west, south, and east) in October 2025.

Analytical Procedures Soil samples were air-dried, ground, and passed through a 2-mm sieve. Soil extracts were prepared with a 1:5 soil-to-water ratio. The pH and Electrical Conductivity (EC) were measured using a pH meter and conductivity meter, respectively. Total Dissolved Solids (TDS) were calculated from EC readings [1]. The concentrations of major cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) and anions (Cl^-, SO_4^{2-}, NO_3^-, NH_4^+) were determined using standard methods, and the results are reported in mill equivalents per liter (meq/L) as shown in Table 1.

Data Analysis Data were classified according to Libyan soil standards and FAO guidelines [2]. The Sodium Adsorption Ratio (SAR) was calculated using the formula:

$$SAR = Na^+ / \sqrt{((Ca^{2+} + Mg^{2+})/2)}$$

Where ion concentrations are in meq/L.

Results and Discussion

Soil pH, Salinity, and Total Dissolved Solids The analytical results for all parameters are presented in Table 1.

Table 1: Physicochemical Characteristics of the Studied Soil Samples

Sample ID	pH (unit) Method	EC µS/cm.	TDS (mg/L)	(meq/L)							
				Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	NO_3^-	NH_4^+
S_1	6.96	240.00	153.30	1.779	0.129	1.187	0.816	1.295	0.25	0.150	0.031
S_2	7.78	225.00	144.00	1.668	0.106	0.52	0.648	1.334	0.347	0.134	0.054
S_3	7.98	435.00	278.40	3.224	0.164	1.258	0.849	2.77	0.404	0.198	0.059
S_4	6.96	392.00	250.88	2.905	0.183	0.976	0.808	2.55	0.206	0.120	0.030
S_5	7.84	321.00	205.44	2.379	0.215	0.76	0.714	2.088	0.480	0.111	0.030
S_6	7.91	311.00	199.04	2.305	0.193	0.87	0.877	2.023	0.272	0.170	0.063
S_7	7.38	190.00	121.60	1.408	0.133	0.737	0.739	0.808	0.309	0.145	0.051
S_8	7.80	1840.00	1177.60	14.207	2.258	5.994	6.495	8.15	1.736	0.232	0.074
S_9	7.81	316.00	202.24	2.342	0.159	0.814	0.758	1.948	0.383	0.163	0.048

Table 2. Physicochemical characteristics of soil extracts from Zuwara city

All ionic concentrations are in meq/L.

The pH of the soils ranged from 6.96 (slightly acidic) to 7.98 (moderately alkaline). Based on Libyan standards, the soils can be classified as follows:

Table 2: Distribution of Soil pH Classes

pH Class	pH Range	Number of Sites	Percentage of Sites (%)
Slightly Acid	**< 7.0**	**2 (S1, S4)**	**22.2%**
Neutral	**7.0-7.5**	**1 (S7)**	**11.1%**

Slightly Alkaline	**7.6-8.0**	**6 (S2, S3, S5, S6, S8, S9)**	**66.7%**
Moderately Alkaline	**8.1-8.5**	**0**	**0%**

The EC values showed significant variation. Sample S8 was an extreme outlier, indicating severe salinity stress.

Table 3: Distribution of Soil Salinity (EC) Classes

Salinity Class	EC Range (μS/cm)	EC Range (dS/m)*	Number of Sites	Percentage of Sites (%)
Non-Saline	< 2000	< 2.0	8 (All except S8)	88.9%
Slightly Saline	2000-4000	2.0-4.0	0	0%
Moderately Saline	4000-8000	4.0-8.0	0	0%
Highly Saline	> 8000	> 8.0	0	0%

1 dS/m = 1000 μS/cm. While S8 (1.84 dS/m) is technically "Non-Saline," its value is alarmingly high compared to the others and approaches the threshold, indicating a serious localized problem.Here is a bar chart visualization representing a comparative analysis o f key parameters across soil samples. It shows concentrations of sodium ions (Na^+), chloride ions (Cl^-), and scaled electrical conductivity (EC, divided by 10) for samples S1 to S9. This chart clearly displays the stark contrast, especially highlighting the elevated Na^+, Cl^-, and EC in sample S8 compared to others

To visualize the stark contrast in salinity and major ion concentrations, a bar chart comparing all samples for key parameters is essential:

Table 4:

To visualize the stark contrast in salinity and major ion concentrations, a bar chart comparing all samples for key parameters is essential:

Sample ID	Na^+ (meq/L)	Cl^- (meq/L)	EC (μS/cm / 10)
S1	1.295	1.779	24
S2	1.334	1.668	22.5
S3	2.77	3.224	43.5
S4	2.55	2.905	39.2
S5	2.088	2.379	32.1
S6	2.023	2.305	31.1
S7	0.808	1.408	19
S8	8.15	14.207	184
S9	1.948	2.342	31.6

Figure 1: Comparative analysis of sodium, chloride, and electrical conductivity (EC scaled down by a factor of 10 for representation) across all samples. Sample S8 shows dramatically higher values.

Major Ionic Composition and Sodium Hazard The ionic composition (Table 1) reveals that chloride (Cl^-) and sodium (Na^+) are the dominant anion and cation, respectively, in the saline sample S8. The high concentrations of Ca^{2+} and Mg^{2+} also contribute to salinity. The calculated SAR value for the critical sample S8 is:

$$SAR\ (S8) = 8.15 / \sqrt{((5.994 + 6.495)/2)} = 8.15 / \sqrt{(6.2445)} = 8.15 / 2.50 = 3.26$$

An SAR value of 3.26 is considered low (Richards, 1954) [3], indicating that while the salinity is high, the sodium hazard for soil structure (i.e., the risk of becoming sodic soil) is currently low. The primary issue is osmotic stress due to high soluble salts, dominated by chlorides and sulfates. The levels of potassium (K^+), an essential nutrient, were also evaluated:

Table 5: Distribution of Exchangeable Potassium Classes

Potassium Class	K^+ (meq/L)	Approx. (ppm)*	Number of Sites	Percentage of Sites (%)
Very Low	< 0.6	< 23.5	8 (All except S8)	88.9%
Low	0.6 - 1.0	23.5 - 39	0	0%
Good	1.0 - 1.8	39 - 70.5	1 (S8)	11.1%
High	1.8 - 3.0	70.5 - 117.5	0	0%
Very High	> 3.0	> 117.5	0	0%

*Conversion: meq/L K^+ * 39.1 ≈ ppm K.*

This indicates that most of the studied soils are deficient in plant-available potassium, which is a significant constraint on fertility.

Physical Chemistry Analysis. The following analyses were performed on the saturated paste extracts. All analyses were performed in triplicate to ensure data quality. pH and Electrical Conductivity (EC): Measured potentiometric ally using a Hach HQ40d pH meter with a PHC10101 probe following the USEPA Electrode Method 8156 [12].Sodium (Na^+) and Potassium (K^+): Determined by flame photometry using the BWB XP digital flame photometer [13].Calcium (Ca^{2+}) and Magnesium (Mg^{2+}): Determined by atomic absorption spectrometry (AAS). Chloride (Cl^-): Analyzed by Mohr argentometric titration. Sulfate (SO_4^{2-}): Measured using the USEPA SulfaVer 4 Method 8051 (2 to 70 mg/L) with powder pillows on a Hach DR 5000 spectrophotometer [14]. Nitrate (NO_3^-): Measured using the Cadmium Reduction Method 8171 (0.1 to 10.0 mg/L NO_3^--N) with NitraVer 5 reagent on a spectrophotometer [15].Ammonium (NH_4^+): Determined by the Salicylate Method (0.01 to 0.50 mg/L NH_3-N) using reagent powder pillows on a spectrophotometer [16]. Data analysis and spatial modeling of Zuwara city Figure 1 is a diagram showing the mechanism of seawater intrusion and its effect on soil salinity and calcification using chemical analysis indicators and

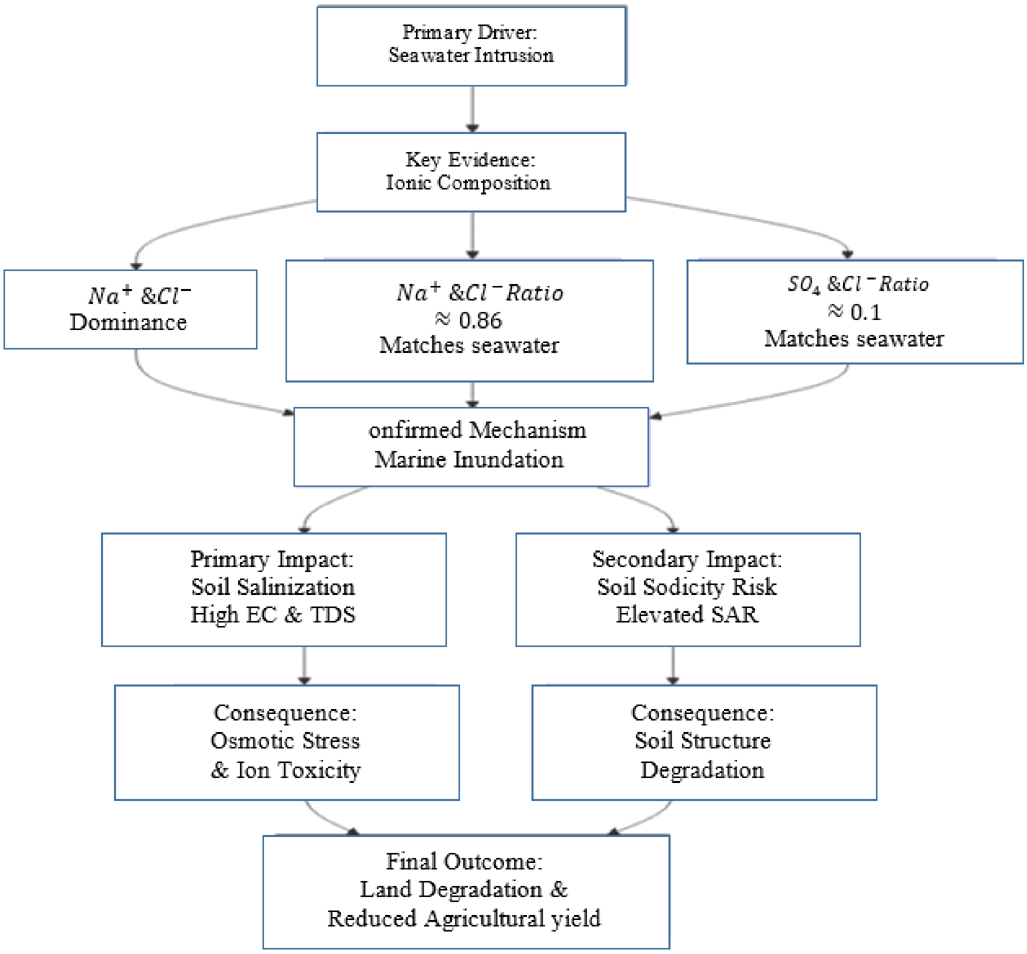

Figure 1.Schematic diagram illustrating the seawater intrusion process and its effects on soil salinity and sodium content in the Zuwara coastal plain,

as revealed by geochemical and spatial analysis. A predictive map of soil salinity (EC) was generated using the **ordinary kriging** interpolation technique in **ArcGIS Pro** to estimate values across the entire study area,

Sodium to Chloride Ratio (Na^+/Cl^-):

$$\mathrm{Na}^+/\mathrm{Cl}^- = \frac{\text{Concentration of Na}^+}{\text{Concentration of Cl}^-}$$

A ratio ≈ 0.86 indicates a match with seawater.[2]

Sulfate to Chloride Ratio ($SO_4{}^{2-}/Cl^-$):

$$\mathrm{SO}_4^{2-}/\mathrm{Cl}^- = \frac{\text{Concentration of SO}_4^{2-}}{\text{Concentration of Cl}^-}$$

A ratio ≈ 0.10 also matches typical seawater values.[2]

Sodium Adsorption Ratio (SAR):

$$SAR = \frac{[\mathrm{Na}^+]}{\sqrt{\frac{[\mathrm{Ca}^{2+}] + [\mathrm{Mg}^{2+}]}{2}}}$$

All concentrations are in milliequivalents per liter (meq/L)

The **Sodium Adsorption Ratio (SAR)** was calculated to assess the relative concentration of sodium to calcium and magnesium and its potential impact on soil structure using the standard formula:

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}}{2}}}$$

Where ion concentrations are in meq/L.

Conductivity meter. Results are expressed in microseconds/cm². Total dissolved solids **(TDS):** Calculated from EC values using an empirical coefficient (TDS (mg/L) ≈ EC (microseconds/cm²) × 0.64). Major cations and anions (Na^+, K^+, $Ca_2{}^+$, $Mg_2{}^+$, Cl^-, $SO_{42}{}^-$, $NO_3{}^-$, and $NH_4{}^+$): Concentrations were determined using ion chromatography or atomic absorption spectroscopy and are expressed in mill equivalents per liter (meq/L).

Assessment Indicators to assess the risk of sodium contamination and its impact on soil structure, the sodium adsorption ratio (**SAR**) was calculated using the standard formula (Richards, 1954). pH and Salinity (EC and TDS) The data in Table 1 show that soil pH ranges from slightly acidic (6.96) to slightly alkaline (7.98), within the acceptable range for most agricultural crops. However, electrical conductivity (EC) values vary significantly: from 190 μS/cm (S7) to 1840 μS/cm (S8). According to the soil salinity classification system (FAO, 2019), samples S1-S7 and S9 are classified as non-saline or slightly saline, while sample S8 is classified as highly saline. Abnormally high EC and TDS values in S8 indicate severe localized pollution. The strong correlation between high values of electrical conductivity (EC), total dissolved solids (TDS), Na^+, Cl^-, Ca^{2+}, Mg^{2+}, and $SO_4{}^{2-}$ in this sample (Mental Map, 2025) indicates an external source of contamination, most likely industrial effluents or seawater intrusion (Rodriguez et al., 2022). . Sodium Absorption Risk (SAR) Assessment For the critical sample S8, the SAR was calculated for the critical sample S8, the SAR coefficient was calculated:

$$SAR_{S8} = \frac{8.15}{\sqrt{\frac{5.994+6.495}{2}}} = \frac{8.15}{\sqrt{6.2445}} = \frac{8.15}{2.499} \approx 3.26$$

SAR value of 3.26 is considered low and indicates that the risk of soil structure degradation due to sodicity is currently low (Richards, 1954). However, such high salt concentrations themselves create osmotic stress for plants.

3. Soil Fertility and Potassium Deficiency Potassium (K^+) analysis revealed a critical issue. With the exception of sample S8, K^+ concentrations in all samples were very low (0.25 - 0.48 meq/L). According to the mental map, 88.9% of the analyzed plots were severely potassium deficient. This seriously limits agricultural productivity, as potassium is vital for plant tolerance to stress, including salinity (Hasanuzzaman et al., 2018). Sample S8, although having a higher absolute K^+ content, also likely has problems with plant potassium availability due to high salinity.

Conclusion and Recommendations

This study identified two main challenges to agricultural soil quality in Zuwarah: 1) severe localized salinization associated with a fixed source of pollution (sample S8), and 2) severe and widespread potassium deficiency, which impairs soil fertility. Based on the findings, the following recommendations are proposed: Urgent Environmental Investigation: Conduct a comprehensive survey of the area surrounding point S8 to identify and eliminate the source of pollution (industrial waste, leaks). Soil Management: Implement soil leaching practices and cultivate salt-tolerant crops (halophilic plants) in the affected areas. Fertility Enhancement Program: Develop and implement a potassium fertilization strategy to address the severe potassium deficiency. Monitoring System Establishment: Establish a long-term monitoring system for soil and water quality to track trends and prevent future degradation.

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