Journal of Engineering and Sustainable Development
Vol. 30, No. 02, March 2026
https://jeasd.uomustansiriyah.edu.iq/index.php/jeasd
ISSN 2520-0917
Research Article
https://doi.org/10.31272/jeasd.3167

Survey and Geospatial Analysis of Soil Salinity and Organic Carbon Dynamics in Garmian District, Iraq

Salim Neimat Azeez[1*], Iraj Rahimi[2,3], Ayad M. Fadhil Al-Quraishi[4]

[1]Protected Cultivation Department, Bakrajo Technical Institute, Sulaimani Polytechnic University, Sulaymaniyah, Iraq
[2]Department of Surveying, Darbandikhan Technical Institute, Sulaimani Polytechnic University, Sulaymaniyah, Iraq
[3]Department of Geosciences, Environment and Spatial Planning, Faculty of Sciences, University of Porto, Porto, Portugal
[4]Petroleum and Mining Engineering Department, Tishk International University, Erbil, Iraq

[*]Email: salim.azeez@spu.edu.iq

Article Info

Received 06/12/2024
Revised 13/12/2025
Accepted 26/12/2025

Abstract

Soil organic carbon (SOC) is crucial for maintaining soil health, as it supports microorganisms, improves soil structure, and regulates nutrient availability. Typically, SOC and salinity exhibit an inverse relationship, influenced by factors such as vegetation, topography, salt composition, and climate. In this study, we mapped soil salinity (ECe: 0.55–3.14 dS/m) and measured SOC (4.5–10.4 g/kg) at 50 field sites. The study employed statistical and spatial analyses, combined with remote sensing and geographic information systems, to quantify the interaction between them. The study found that SOC generally declines with increasing salinity, with a clear threshold at 1.43 dS/m. Beyond this threshold, further SOC loss slows, likely due to the mitigating effects of salinity-tolerant grasses and calcium-rich parent material on sodium stress. Vegetation cover (short grasses occupying 29.3 % of the area) helped sustain soil organic carbon even under higher salinity. These findings align with our research objectives by quantifying the relationship between SOC and salinity and identifying the primary factors that control it. The results suggest that promoting salinity-tolerant vegetation and applying calcium-based amendments are effective strategies for maintaining SOC levels in semiarid, calcareous soils. The study findings provide actionable spatial guidance for targeted soil management and ecological planning in similar regions.

Keywords: Soil Organic Carbon, Soil Salinity, Normalized Difference Vegetation Index (NDVI), Wild Barley.

1. Introduction

Soil salinity and soil organic carbon (SOC) are crucial indicators of soil health, playing significant roles in agricultural productivity, ecosystem resilience, and the global carbon cycle. The buildup of soluble salts leads to soil salinity, which affects approximately 20% of the world's irrigated farmland, exacerbating land degradation and increasing food insecurity, particularly in dry and semiarid areas [1]. Worldwide, these impacts threaten food security and the terrestrial carbon sink, making the study of SOC-salinity interactions crucial for both local land management and global climate goals. At the same time, SOC is fundamental to soil fertility, water retention, and mitigating climate change by sequestering atmospheric carbon dioxide [2]. The relationship between these two factors is complex; for instance, increased salinity can hinder SOC accumulation by reducing microbial activity and plant growth, whereas soils rich in SOC may improve salinity tolerance due to their improved soil structure [3]. An inverse relationship exists between soil salinity and SOC, which has substantial implications for global challenges such as climate change and land degradation [4].

The relationship between soil salinity and SOC showed that SOC decreased significantly with increasing soil salinity [5]. Therefore, grasping their spatial dynamics is vital for effective land management and adapting to climate change. Given rising global concerns over land degradation and carbon sequestration, understanding these dynamics at local scales can inform broader mitigation strategies. The study of SOC is of great importance, as it enables the determination of the amount of organic matter in the soil using the equation (Organic matter = Organic Carbon × 1.72) [6],[7]. This includes knowledge of soil fertility as organic carbon is a crucial element in soil, water, energy sources, plant production, and food security, with positive effects on rice observed [8]. The quality of soil, agricultural yield, and environmental sustainability are significantly influenced by two key factors: soil salinity and

SOC. Understanding how soil salinity and SOC are distributed across the land is crucial for effective land management and ensuring sustainable farming practices. In dry and partly dry areas, soil salinity poses a significant environmental challenge because excessive salt accumulation harms the soil and reduces its ability to produce crops [4].

On the other hand, SOC is essential for maintaining soil health, capturing carbon, and contributing to the fight against climate change. However, its distribution across areas is affected by both natural elements and human activities [9]. New developments in geospatial technologies, such as remote sensing (RS) and geographic information systems (GIS), have enabled the detailed mapping and analysis of soil properties across diverse terrains [1]. In arid or semiarid regions, soil salinity poses a significant problem. When there is excessive salt buildup, it can harm the soil structure, reduce water availability, and hinder plant growth, ultimately decreasing agricultural outputs [10].

On the other hand, SOC is essential for maintaining nutrient-rich soils, enhancing microbial activity, and facilitating carbon storage, thereby mitigating the impacts of climate change [5]. The relationship between these two factors is intricate. Higher salinity may damage soil structure and reduce SOC levels, but SOC can also affect soil quality and its ability to withstand salinity [11]. In particular, distinct ecosystems, such as salt marshes and mangrove forests, exhibit higher salinity, which is associated with greater SOC accumulation because microbial degradation is reduced [12]. The overall effect of soil salinity on SOC remains unclear and warrants further investigation [13].

The use of geospatial analysis has become an effective method for tracking and mapping soil salinity and SOC across large areas, primarily through the integration of remote sensing and GIS [14]. For example, in a study by Lekka et al. [15] and Wang et al. [16], geospatial analysis methods were employed to investigate the impact of salinity on SOC. Recent advances in satellite hyperspectral imaging, machine learning techniques, and digital soil mapping have enabled scientists to evaluate spatial differences in soil characteristics with high precision [17]. These methods enable the quick identification of soil deterioration patterns and support precision farming techniques that enhance land management activities. An increasing number of studies have emphasized the importance of using remote sensing data, including Sentinel-2, Landsat, and MODIS, in conjunction with machine learning models to forecast SOC content and salinity levels [18]. Recent advances in geospatial technology have revolutionized soil studies by integrating satellite imagery, spectral indices, and predictive modeling to assess soil salinity and SOC variability.

Sensors used in multispectral and hyperspectral remote sensing, such as Landsat-8 OLI, Sentinel-2 Multispectral Instrument (MSI), Moderate Resolution Imaging Spectroradiometer (MODIS), and WorldView-3, have been extensively used to identify the spectral characteristics of salt-impacted soils and the distribution of organic carbon [14]. Recent developments in geospatial technology, including remote sensing, machine learning, and GIS, have significantly enhanced the monitoring and prediction of soil properties, providing new levels of spatial and temporal detail. Multispectral and hyperspectral satellite images, such as those from Sentinel-2 and Landsat, enable the identification of salinity-induced changes in spectral reflectance. Meanwhile, machine learning methods, such as random forests and neural networks, help integrate geospatial information with ground data to understand SOC variability [10], [19]. Kalambukattu et al. [20] conducted research in the Indo-Gangetic Plains and demonstrated that combining soil electrical conductivity data with vegetation indices in hybrid models effectively maps areas with high salinity.

Similarly, digital soil mapping (DSM) methods have been used to predict SOC levels in damaged coastal areas, revealing a strong correlation between SOC decline and saltwater intrusion [21]. However, spatiotemporal differences in soil salinity and SOC make it difficult to evaluate them jointly. Local factors, such as irrigation methods, land-use changes, and extreme weather conditions (e.g., droughts and sea-level rise), shape their interactions, underscoring the need for studies focused on specific areas [22]. Soil salinity and water scarcity are significant environmental issues that substantially affect soil functions and the decomposition of soil organic matter. Although they are crucial, the combined effects of low water and salinity on residue breakdown remain largely unexplored. When drought and salinity occur simultaneously, they can negatively affect microbial activity, particularly when fresh plant material is present [23].

Crop production and food security are significantly affected by soil salinity. Therefore, developing salt-tolerant crops is the most effective means of addressing this type of environmental stress [24]. Although progress has been made, gaps in knowledge persist regarding how these connections vary across levels and across climate change scenarios, particularly in regions such as Africa and South Asia, where data are limited. Boubehziz et al. [25] highlighted that integrating SOC studies with geoinformation technologies yields valuable insights into the spatial variability of SOC, producing detailed maps that describe both the quantity and quality of SOC in soils of semiarid regions. These maps are invaluable for future studies and significantly contribute to the understanding of soil dynamics in these areas. This study, therefore, tests the hypothesis that, beyond a certain salinity threshold, biological and geochemical factors buffer SOC loss. We focus on the Garmian district of the Kurdistan Region, Iraq, which features semiarid, calcareous soils underlain by calcium-rich parent material and dominated by halophytic grasses. These unique characteristics, complex topography, dominant cover of wild barley, and moderate salinity levels make Garmian an ideal natural laboratory for examining how local biophysical controls modulate SOC–salinity relationships. The objectives of this study were as follows:

1. The statistical and spatial relationships between soil salinity and SOC.
2. Examine the factors influencing the spatial variability of soil salinity and SOC.
3. Identification of additional factors affecting the interaction between soil salinity and SOC.

4. Spatial maps were developed to characterize the relationship between soil salinity, soil organic carbon, and vegetation cover.

2. Materials and Methods

2.1. Study Area

This study was conducted in the Garmian district of the Kurdistan Region of Iraq (KRI), covering an area of 4037.728 km². The study area is geographically bounded to the north by the city of Darbandikhan, to the south by the city of Kalar, to the west by villages near the cities of Kifri and Chamchamal, and to the east by villages situated near the Iraqi-Iranian border, as shown in Fig. 1.

The study area is situated between longitudes of 44°49′49″E and 45°43′50″E and latitudes of 34°35′44″N and 35°12′37″ N. The elevation of the area ranges from 165 to 70 m above sea level. According to Kharrufa [26], the region experiences a semiarid continental climate, with seasonal rainfall averaging 336 mm per year. Temperature variations were significant, with average winter temperatures of approximately 10°C and summer temperatures reaching approximately 40°C (Garmian Agricultural Office and Derbendikhan Dam Office).

Geologically, as described by Buringh [27], the study area is located within the foothills of the Zagros Mountains, whereas tectonically, it lies within the folded zone [28]. The soils in the region are predominantly non-irrigated, with limited areas cultivated with economic crops, such as wheat (Triticum spp.) and barley (Hordeum spp.), relying mainly on rainfall. The landscape also supports extensive growth of natural vegetation, particularly short grasses, with wild barley (Hordeum spontaneum) being widespread [29]. According to the modern American soil classification system, the soils in the study area belong to the Aridisols order [30]. The soil moisture regime is classified as Torric [31], while the soil temperature regime is identified as Hyperthermic [32]. The study area is mountainous in the north, whereas the central region is undulating and interspersed with hills. On the southern side, the terrain is undulating to flat.

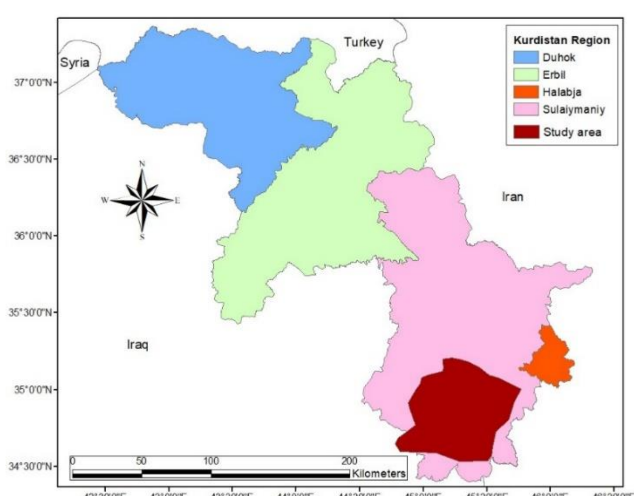

Figure 1. Study area location map

2.2. Methodology Overview

The study employed two approaches: the collection of field data and the utilization of Landsat satellite imagery to assess how remote sensing (RS) and GIS techniques can be applied to identify soil salinity and SOC distribution within the study area. The framework outlined in Fig. 2 illustrates the methodology used to obtain the anticipated results.

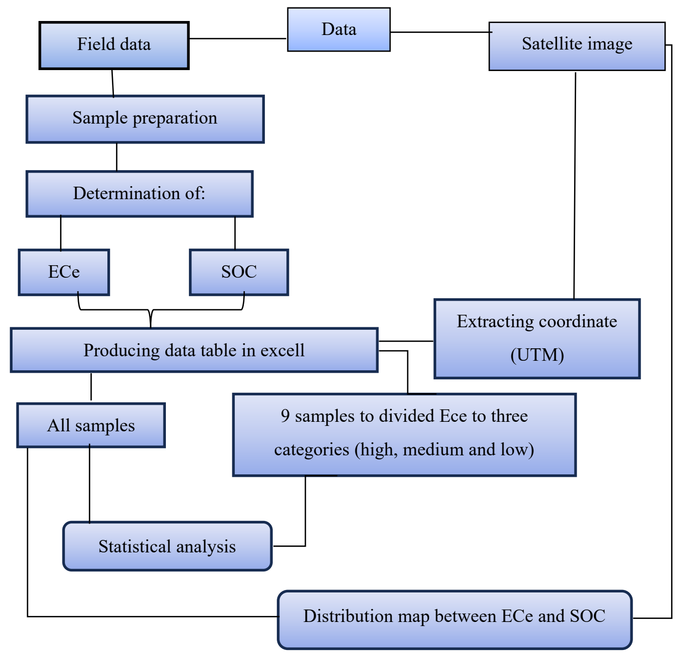

Figure 2. Outline framework, data collection, determination, processing, analysis, and expected results.

2.3. Data Used

This study was conducted in the Garmian district using two types of datasets. The first dataset consisted of field data, including 50 surface soil samples (collected according to the nature of the study area), collected at depths of 0–30 cm. Table 1 presents the characteristics of these samples, detailing soil salinity measured as electrical conductivity (ECe, ds/m), SOC (g/kg soil), and their spatial coordinates represented in the Universal Transverse Mercator (UTM) coordinate system. The UTM coordinates were obtained using the World Geodetic System 1984 (WGS 1984) with Zone 38 datum.

During data collection, we encountered challenges related to the large extent of the study area and its rugged topography, particularly in the northern region. These conditions made some areas difficult to access. To address this, we extended the data collection period, which allowed us to reach the necessary locations and ensure comprehensive coverage.

The second dataset utilized was the Landsat 9 Collection 2 Level 1 imagery from the Operational Land Imager/Thermal Infrared Sensor (Landsat 9 OLI/TIRS C2 L1) provided by the United States Geological Survey (USGS). The image captured on May 29, 2024 (Fig. 3) featured clear vegetation cover, enabling the assessment of soil salinity effects on vegetation, with no cloud cover (0%). Landsat 9 comprises eleven spectral bands, including Coastal Aerosol, Visible and Near-Infrared (VNIR), Short-Wavelength Infrared (SWIR 1 and 2), Panchromatic, Cirrus, and Thermal bands 1 and 2, as detailed in Table 2 [33].

Table 1. The soil sample number, Ece, SOC, and their coordinates.

NO.	Ece (ds/m)	SOC (g/kg)	X (m)	Y (m)
1	2.3	4.5	497256.4	3844464
2	1.07	6.07	508244.5	3843229
3	0.99	7.18	514634	3839158
4	1.08	12.09	529671.7	3833930
5	0.96	5.4	533986.3	3840210
6	0.66	11	546607	3836175

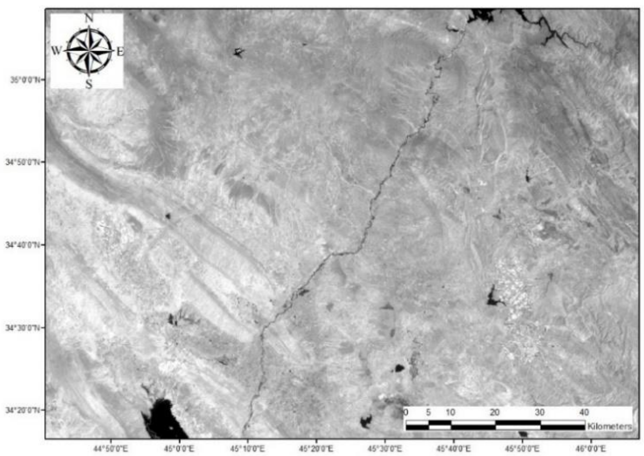

Figure 3. The image was captured on May 29, 2024.

Table 2. Landsat 9 Spectral Bands and Spatial Resolutions [33].

Band	Band Designation	Band Edges (nm)	GIFOV (m)
1	Coastal Aerosol (CA)	435 – 450	30
2	Blue	452 – 512	30
3	Green	533 – 589	30
4	Red	636 – 673	30
5	Near IR (NIR)	850 – 879	30
6	SWIR 1	1565 – 1651	30
7	SWIR 2	2105 – 2295	30
8	Panchromatic	503 – 675	15
9	Cirrus	1364 – 1384	30
10	Thermal 1	10450 – 11200	100
11	Thermal 2	11580 – 12500	100

2.4. Dataset used for Image Processing

The study was conducted in four main phases. First, relevant information about the study area was gathered, including soil type, vegetation cover, prevailing climate, and geology, along with laboratory tests to assess soil salinity and SOC. Second, the required data, including soil salinity, SOC, and the coordinate system, were entered into Microsoft Excel spreadsheets, where statistical analyses were performed to determine the relationship between soil salinity and SOC. To examine the relationship between soil salinity and SOC, a simple linear regression model was employed.

This model was used to quantify the strength and direction of the relationship between the electrical conductivity of the soil saturation extract (ECe), representing salinity, and the SOC content. A linear equation was used to calculate Y and R^2, followed by the generation of relevant charts. Third, satellite imagery was imported into ArcGIS ver. 10.8.2, where analysis was carried out using bands 4 (RED) and 5 (NIR) to assess vegetation cover, and the Normalized Difference Vegetation Index (NDVI) was calculated using (1).

$$NDVI = (NIR - RED)/(NIR + RED) \quad (1)$$

The data from the Excel spreadsheet were imported into ArcGIS and overlaid on the NDVI map shown in Fig. 4 to analyze the relationships among soil salinity, SOC, and NDVI. This process enabled the interpretation of complex interactions between variables, resulting in the generation of corresponding maps.

2.5. Samples Laboratory Analysis

The collection and analysis of soil samples in the study area involved selecting 50 samples using a grid system based on a topographic map [34]. The sample points were selected to ensure good spatial distribution and were based on the topographic characteristics, accessibility, and observable soil morphology of the study area. The global coordinates of each sample were recorded using the Garmin GPS device. Table 1 presents a list of ten representative samples. The soil samples were dried and sieved through a 2-millimeter mesh, after which soil salinity was assessed by measuring the Ece of the soil extract following the method outlined in [35]. Additionally, the SOC was determined using the Walkley-Black method, as described in [36] and referenced in [37].

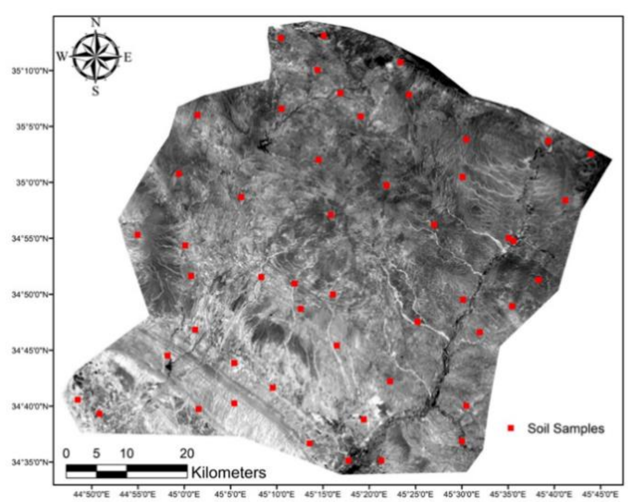

Figure 4. Sample distribution map in the study area.

2.6. GIS-Based and Statistical Analysis

The analysis was conducted in two main directions: first, the soil salinity data for all 50 samples, represented by ECe, were collected and subjected to statistical and GIS-based analysis; second, for greater clarity, the soil salinity values were categorized into three levels (Low, Medium, and High) and further divided into nine categories, ranging from the lowest value of 0.51 ds/m to the highest value of 3.14 ds/m, as shown in Table 3. Statistical and GIS-based analyses were performed on the categorized data.

Table 3. Classes of soil salinity of the study area.

NO.	Ece (ds/m)		Organic carbon (g/kg)
1	Low	0.51	8.25
2		0.52	10.4
3		0.55	7.34
4	Medium	1.43	4.66
5		1.58	4.7
6		1.79	4.58
7	High	2.3	4.5
8		3.08	4.63
9		3.14	4.51

3. Results and Discussion

The findings showed an inverse relationship between soil salinity and SOC, with SOC content generally decreasing as soil salinity, as indicated by ECe, increased. Increased soil salinity reduces plant productivity, thereby limiting the input of organic carbon to the soil. Additionally, soil salinity inhibits microbial activity, slowing the decomposition of organic residues and reducing soil organic carbon levels. These findings are consistent with those in [38]. The column chart presented in Fig. 5, which incorporates data from all 50 samples, illustrates this inverse relationship: as soil salinity decreases, SOC increases; conversely, as soil salinity rises, SOC decreases.

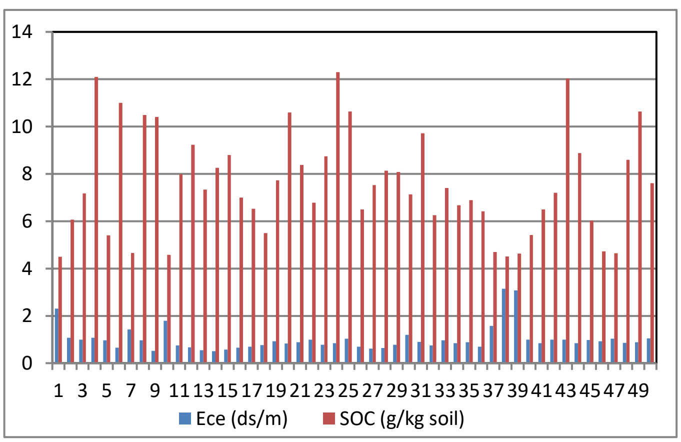

Figure 5. The relationship between soil salinity and SOC for 50 samples.

As illustrated in Fig. 6, the equation revealed a negative slope value of -1.8435, indicating an inverse relationship between soil salinity and SOC. The coefficient of determination (R^2) was 0.2064, indicating that 20.64% of the variation in SOC was strongly influenced by soil salinity. However, this inverse relationship appears relatively weak, likely attributable to the study area's complex, varied topography, characterized by mountains, hills, plains, and valleys.
Additionally, other factors such as salt type, vegetation cover, parent material, topography, rainfall, temperature, and soil pH likely mitigate the impact of soil salinity on SOC.

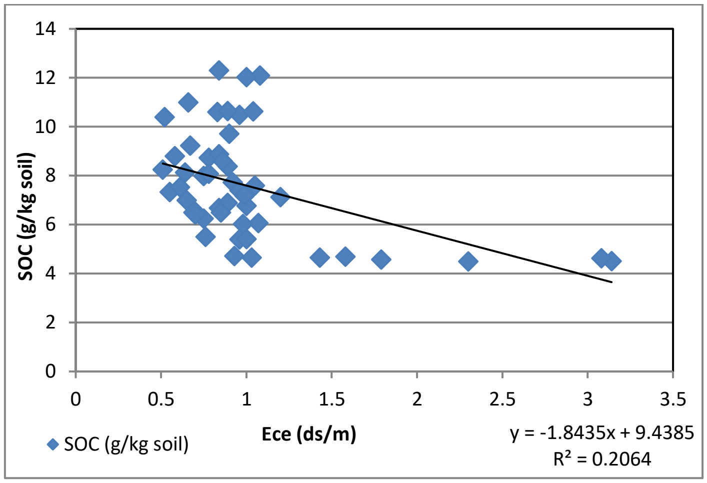

Figure 6. Linear equation and R^2 value of the relation between soil salinity and SOC for 50 samples.

However, according to the United States Salinity Laboratory Staff [35], the soils in this study are not classified as saline, as saline soils are defined by an electrical conductivity (EC) greater than 4 dS/m. The maximum EC value observed in our samples was 3.14 ds/m, as shown in Table 4. Although this value still had some effect, it did not significantly impact plant growth or the microorganisms responsible for decomposing plant material and producing organic carbon. Although salinity influences SOC, its effect is not sufficiently strong to produce a perfect inverse relationship, as indicated by the R^2 value, which is far from 1.

Furthermore, the relationship between soil salinity and SOC varied depending on the location of the samples within the study area. In some cases, the influence of soil salinity on SOC was minimal, likely due to factors such as the type of salts present, vegetation cover, parent material, topography, rainfall, temperature, and soil pH. For example, Zubaidi [39] noted that plants, particularly grasses, which are abundant in the study area, use soil moisture for transpiration, thereby reducing the evaporation of soil solutions and groundwater. This, in turn, limits the accumulation of salts on the soil surface where organic matter and plant residues are found.

Table 4. Classification of soil salinity according to the United States Salinity Laboratory staff.

Soil salinity class	Electric conductivity	pH	Exchangeable sodium percentage (ESP)
Non-Saline Soils	< 4	< 8.5	< 15
Saline Soils	> 4	< 8.5	< 15
Saline-Sodic Soils	> 4	< 8.5	< 15
Sodic Soils	< 4	> 8.5	< 15

Generally, the rate of salinization is lower in vegetated land than in exposed, non-vegetated land, as illustrated in Fig. 7.

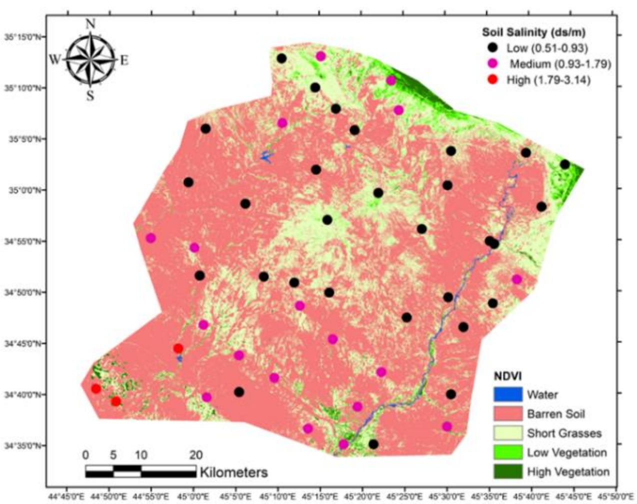

Figure 7. Distribution of soil salinity classes.

The southern areas, with sparse vegetation cover, exhibit higher levels of salinity than the northern areas, which are characterized by dense vegetation. This difference can be attributed to the parent material of the study area, which is rich in calcium carbonate [40]. The presence of calcium ions facilitates the replacement of sodium ions, thereby mitigating the harmful effects of sodium salts in plants. As a result, the increased availability of organic matter contributes to an increase in SOC.

High sodium concentrations are toxic to most plants and pose significant abiotic stresses to plant growth and productivity, resulting in reduced soil organic matter (SOM) and SOC levels. However, calcium has been identified as a key factor in enhancing plant tolerance to salinity by providing protective effects in saline soils. It plays a critical role in maintaining the structural and functional integrity of plant cell membranes, stabilizing cell wall structures, regulating ion transport and selectivity, and controlling ion exchange processes and cell wall enzyme activity. These functions help mitigate the adverse effects of sodium salts [41].

Grasses and wild plants with small leaves, such as wild barley (Hordeum spontaneum), a common plant in the study area, are considered salinity-tolerant owing to genetic factors. These genes regulate osmotic balance even in saline environments [42]. According to studies by Hoseinzadeh et al. [43], Taketa et al. [44], and Zhang and Murray [45], wild barley varieties are a crucial resource for breeding programs focused on soil salinity tolerance, as they exhibit higher resilience to saline soils than other plants. Plant tolerance to salinity varies depending on the developmental stage and genotype. Additionally, the geographical origin of the plant influences its tolerance, with plants from different regions likely exhibiting varying levels of salinity resistance based on local soil conditions [46]. As shown in the NDVI map (Fig. 8) and Table 5, the vegetation cover classes were categorized by vegetation density. The category dominated by short grasses, including wild barley, covered 1282.604 km² (29.339% of the study area). These salinity-tolerant plants contributed to the observed inverse yet weak relationship between soil salinity and SOC. Despite increased salinity, SOC levels did not decrease significantly, likely because of these plants' tolerance and the relatively low soil salinity in the study area.

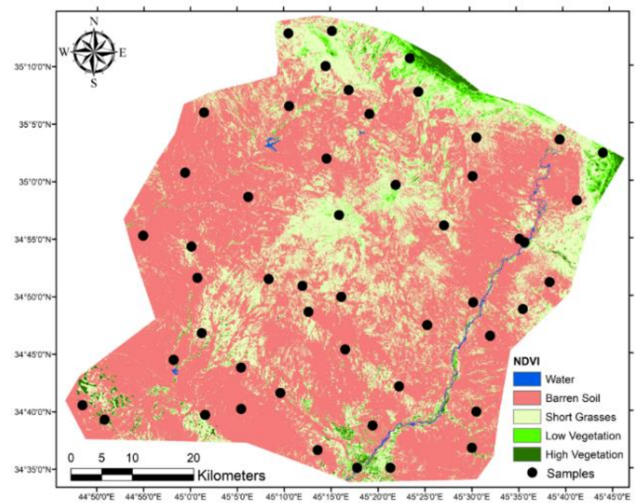

Figure 8. NDVI classes of the study area.

Table 5. Percentage and classes of NDVI.

NDVI Classes	Percentage	Area (Km^2)
Water	0.343	14.974
Barren Soil	65.944	2882.888
Short Grasses	29.339	1282.604
Low Vegetation	2.844	124.348
High Vegetation	1.531	66.914
Total	**100.000**	**4371.728**

However, when considering the nine samples from Table 3, which represent the minimum, median, and maximum soil salinity levels, a clearer and stronger inverse relationship emerges, as shown in the column chart (Fig. 9).

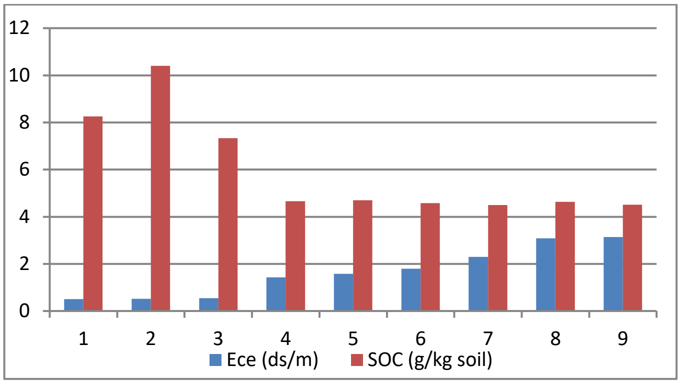

Figure 9. Column chart of the relation between soil salinity and SOC for nine samples.

Generally, SOC levels increase as soil salinity decreases and vice versa. This pattern is attributed to the negative impact of soil salinity on soil organisms, particularly microorganisms, which reduce the decomposition of organic matter and plant residues, thereby lowering SOC. Moreover, soil salinity has a detrimental effect on plant growth, further contributing to a decline in the SOM and SOC. Salinity interferes with several critical aspects of plant growth, including seed germination, vegetative growth, and reproductive development [47]. It affects complex interactions within morphological, physiological, and biochemical processes, influencing water and nutrient absorption and affecting nearly all stages of plant growth, from seed germination to vegetative and reproductive development [48]. This results in a decrease in soil organic carbon levels.

A strong inverse relationship between soil salinity and SOC is clearly demonstrated in Fig. 10 when the (ECe) values are divided into three categories: minimum, middle, and maximum (Table 3). The linear equation had a slope of -1.6352, indicating an inverse correlation between soil salinity and SOC. An R^2 value of 0.6007 indicates that 60.07% of the variation in SOC is explained by soil salinity, suggesting a strong relationship. It is noteworthy that the R^2 for the categorized salinity levels (0.6007) indicates a greater impact of soil salinity when classified into three categories than the lower R^2 of 0.2064 for the total salinity values.

As shown in Table 3, there was a distinct difference in SOC between the minimum soil salinity category and the middle and maximum categories. The lowest SOC value of 7.34 g/kg is recorded at ECe 0.55 ds/m, and SOC decreases sharply to 4.66 g/kg at the middle limit of ECe 1.43 ds/m. These substantial decreases continued even as soil salinity reached the highest value of 3.14 ds/m, at which SOC was 4.51 g/kg, indicating a slight difference between the mid- and maximum ECe values. This indicates that low soil salinity has minimal effects on SOC; however, when salinity exceeds the intermediate threshold of 1.43 ds/m, its impact becomes more pronounced. Therefore, the effective threshold for the influence of soil salinity on SOC appeared to be 1.43 ds/m. Beyond this point, the reduction in SOC levels was less pronounced, suggesting that plants, especially small herbaceous plants such as wild barley, which are halophytic and tolerate soil salinity, exhibit an adaptive response to higher salinity levels [49].

This explains why the relationship between soil salinity concentrations and the amount of SOM and SOC is complex and contradictory. The rates of OM decomposition into SOC, as well as the decomposition of SOC itself, vary with soil salinity, and this complex relationship changes with different salinity levels. Soil salinity impedes plant growth, leading to reduced aboveground biomass, which in turn decreases OM content and subsequently reduces SOC [50]. However, increased soil salinity diminishes microbial activity, slowing the decomposition of SOC and consequently increasing its levels. This phenomenon was observed when soil salinity increased from 1.43 ds/m to 3.14 ds/m (a 1.72 ds/m increase), yet SOC levels did not decrease. This lack of decrease can be attributed to reduced microbial activity responsible for SOC decomposition, which allows SOC to remain high despite rising salinity. These findings are consistent with those reported in [19].

The observed salinity threshold of 1.43 ds/m, beyond which soil salinity significantly affects SOC, aligns with findings in similar semiarid and arid ecosystems globally. For instance, Mzid et al. [18] have observed significant declines in SOC at salinity levels exceeding 1.5 dS/m, attributing this to inhibited microbial activity and reduced plant biomass. In coastal wetlands, Lekka et al. [15] reported that even moderate salinity levels (approximately 1.0–2.0 ds/m) reduce microbial decomposition rates, thereby altering SOC dynamics. Similar to the Garmian district, the impact of salinity was found to be moderated by the kind of vegetation cover, with halophytic species reducing SOC losses in saline soils [51].

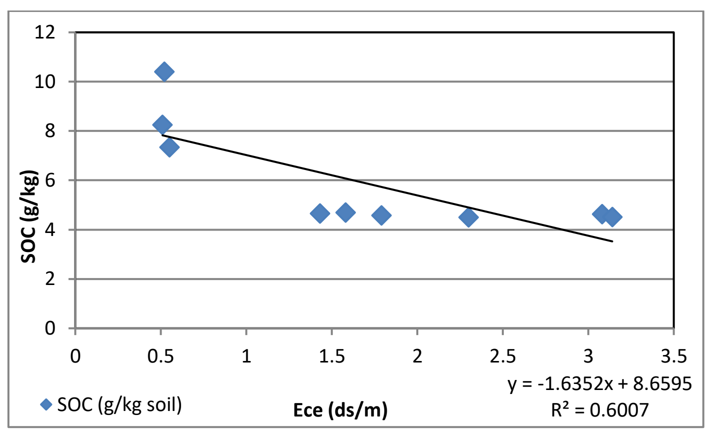

Figure 10. Linear equation and R^2 value of the relation between soil salinity and SOC for nine samples.

One key limitation is the accessibility challenges in rugged areas of the study site, which constrained the spatial distribution of some soil sampling points. Moreover, although NDVI is a valuable proxy for vegetation cover, it may not fully capture the complexity of plant-soil interactions or distinguish among vegetation types with differing salinity tolerances. The use of categorized salinity levels, while improving correlation, may also simplify the natural variability of soil salinity in the landscape. Lastly, the study was based on a single time-period dataset, limiting the ability to observe seasonal or long-term dynamics. Acknowledging these limitations helps contextualize the results and provides direction for future research.

Salinity thresholds for SOC differ between the Mediterranean and South Asia, influenced by soil type, climate, and vegetation. For instance, in agricultural soils in northeastern China, SOC decreased sharply at salinity levels greater than 2.0 dS/m, resulting in low crop yields and limited organic inputs [5]. On the other hand, soils in Australia that were rich in calcium minerals (cambic horizon facies) were resistant to saline conditions, indicating that, compared with the Garmian region, soil solutions high in calcium ions can neutralize excess sodium ions, resulting in the undisturbed condition of soils [52]. These comparisons also highlight the local control of salinity thresholds and the partitioning of soil moisture between vegetation and soil. Soil salinity, due to environmental and natural processes and anthropogenic activities, is a limiting factor for crop growth and environmental sustainability [53],[54]. Environmental and natural causes were focused mainly on the study area, including low precipitation and wind weathering, which was particularly pronounced in southern areas due to frequent winds and limited vegetation cover. This is what Gojiya et al. [55] said. Soil salts hinder the growth of plants and lower soil fertility value, which reduces agricultural production as well as vegetation cover, as observed in Fig. 7, in which coverage of vegetation declined with the increase in soil salinity This was stated in [56]. GIS and RS are leading technologies for monitoring and managing soil salinity. Using satellite images we made accurate maps of the spatial distribution and identification of salinity affected areas (Fig. 6). In addition, by combining the Geographic and spatial survey data with statistical method, we have improved the accuracy of identifying in study area soil salinity, interpreted effectively the relationship between Soil Salinity and Soil or plant growth in that region, which can reduce large-scale monitoring cost as both2 demonstrated [57].

4. Conclusions

A negative relationship was found between soil salinity and SOC concentration at the large scale, but the strength and direction of the relationship differed across salinity levels. Initially, the inverse correlation was not statistically significant due to other environmental and geographical factors in their study area that may be affected by the full range of soil salinity. However, when we used the nine selected values of minimum, medium, and maximum soil salinity ranges for this analysis, we observed a stronger negative relationship. Clearly, the critical soil salinity threshold was estimated at 1.43 ds/m above that of the salt treatment; plants adapted to higher salinity, and the detrimental impact on plant health was mitigated. Therefore, SOC stock loss was less severe, particularly when the area was characterized by small, salt-tolerant herbaceous plants, such as wild barley, which helped maintain relatively stable SOC levels even under increased salinity.

Soil salinity has a significant impact on SOC, which in turn affects soil management techniques. High salinity levels can impede the decomposition of organic matter, reducing the soil's organic carbon content and, consequently, its fertility. Therefore, successful soil management practices must address both organic carbon enrichment and salt mitigation to preserve soil health and productivity.

These findings underscore the crucial need for targeted soil management strategies to maintain SOC levels in saline environments. Key measures include the following.

1. Promoting vegetative cover: Stabilize SOC levels and encourage the growth of salinity-tolerant plant species, such as wild barley. These plants mitigate the impact of salinity by enhancing soil structure and incorporating organic inputs. Agroforestry systems incorporating halophytes can enhance soil resilience in semiarid and arid regions.
2. Calcium amendments: This study emphasized the role of calcium in mitigating the effects of sodium. Soil amendments, such as gypsum, could replace exchangeable sodium with calcium, enhancing soil fertility and structure while supporting plant growth.
3. Irrigation management: Implementing controlled irrigation systems, such as drip irrigation, can minimize salinity buildup by reducing evaporation rates, particularly in regions reliant on groundwater with a high salt content.
4. Adopting precision agriculture techniques: RS and GIS techniques to monitor salinity and SOC variability. This enables the identification of high-risk areas and the design of localized interventions. These technologies can also support predictive modeling of future salinity trends under climate change scenarios.
5. Improving organic inputs: The regular addition of organic matter, such as compost or biochar, can enhance microbial activity and mitigate salinity-induced SOC loss by providing substrates for microbial decomposition.

In addition to the measures already discussed, we recommend the following actions:

1. Incorporate deep-rooted, salt-tolerant cover crops (e.g., saltbush, alfalfa) into existing rotations to break up soil compaction, enhance water infiltration, and draw salts deeper below the root zone, thereby protecting SOC in surface layers.
2. Establish a network of in-situ salinity sensors and periodic soil sampling stations across salinity gradients. Continuous data collection will enable early warning of salt hotspots, facilitate adaptive management, and improve the precision of their early detection, thereby enhancing the accuracy of RS/GIS-based salinity maps.
3. Developing local extension programs to train farmers and land managers on interpreting SOC–salinity maps, applying gypsum and organic amendments correctly, and adopting precision irrigation techniques. Empowered stakeholders are better able to implement and sustain the recommended practices over the long term. Because soil salinity and SOC management are global issues, particularly in regions experiencing drought and low rainfall, they are significant.

4. We recommend further research on this topic, especially in the study area.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Authors' Contributions

Salim Neimat Azeez proposed the research problem, conducted field and laboratory work, produced maps, figures, and tables, interpreted the results, and drafted the manuscript.

Iraj Rahimi analyzed the study results.

Ayad M. Fadhil Al-Quraishi reviewed, edited, and enhanced the manuscript.

All authors have discussed the results and contributed to the final manuscript.

References

[1] FAO, "Global map of salt-affected soils," Food and Agriculture Organization of the United Nations, 2021. [Online]. https://openknowledge.fao.org/handle/20.500.14283/cb7247en.

[2] M. J. Nazir, G. Li, M. M. Nazir, F. Zulfiqar, K. H. Siddique, B. Iqbal, and D. Du, "Harnessing Soil Carbon Sequestration to Address Climate Change Challenges in Agriculture," *Soil and Tillage Research*, vol. 237, p. 105959, 2024. doi: https://doi.org/10.1016/j.still.2023.105959

[3] J. Jia, J. Zhang, Y. Li, L. Koziol, L. Podzikowski, M. Delgado-Baquerizo, G. Wang, and J. Zhang, "Relationships between soil biodiversity and multifunctionality in croplands depend on salinity and organic matter," *Geoderma,* vol. 429, p. 116273, 2023. doi: https://doi.org/10.1016/j.geoderma.2022.116273

[4] A. Hassani, P. Smith, and N. Shokri, "Negative correlation between soil salinity and soil organic carbon variability," *Proceedings of the National Academy of Sciences,* vol. 121, no. 18, e2317332121, 2024. doi: https://doi.org/10.1073/pnas.2317332121

[5] W. Zhang, W. Zhang, Y. Liu, J. Zhang, L. Yang, Z. Wang, Z. Mao, S. Qi, C. Zhang, and Z. Yin, "The role of soil salinization in shaping the spatio-temporal patterns of soil organic carbon stock," *Remote Sensing*, vol. 14, no. 13, p. 3204, 2022. doi: https://doi.org/10.3390/rs14133204

[6] M. L. Jackson, "Soil Chemical Analysis", Prentice-Hall, 1958.

[7] D. W. Nelson and L. E. Sommer, "Total carbon, organic carbon, and organic matter," in *Methods of Soil Analysis*, 2nd ed., Madison, WI: ASA and SSSA, 1982, pp. 539–579.

[8] X. Wu, L. Wang, J. An, Y. Wang, H. Song, Y. Wu, and Q. Liu, "Relationship between soil organic carbon, soil nutrients, and land use in Linyi city (east China)," *Sustainability*, vol. 14, no. 20, p. 13585, 2022. doi: https://doi.org/10.3390/su142013585

[9] Y. Zhou, X. Zhao, X. Guo, and Y. Li, "Mapping of soil organic carbon using machine learning models: Combination of optical and radar remote sensing data," *Soil Science Society of America Journal*, vol. 86, no. 2, pp. 293-310, 2022. doi: https://doi.org/10.1002/saj2.20371

[10] P. Tarolli, J. Luo, E. Park, G. Barcaccia, and R. Masin, "Soil salinization in agriculture: mitigation and adaptation strategies combining nature-based solutions and bioengineering," *iScience*, vol. 27, no. 2, p. 108830, 2024. doi: https://doi.org/10.1016/j.isci.2024.108830

[11] W. He, H. Wang, W. Ye, Y. Tian, G. Hu, Y. Lou, H. Pan, Q. Yang, and Y. Zhuge, "Distinct stabilization characteristics of organic carbon in coastal salt-affected soils with different salinity under straw return management," *Land Degradation & Development*, vol. 33, no. 13, pp. 2246-2257, 2022. doi: https://doi.org/10.1002/ldr.4276

[12] H. Erb, A. Keiser, and K. M. DeAngelis, "Salt marsh soil organic carbon is regulated by drivers of microbial activity," *Sustainable Microbiology*, vol. 1, no. 1, p. qvae009, 2024. doi: https://doi.org/10.1093/sumbio/qvae009

[13] Z. Haj-Amor, T. Araya, D.-G. Kim, S. Bouri, J. Lee, W. Ghiloufi, Y. Yang, H. Kang, M. K. Jhariya, A. Banerjee, and R. Lal, " Soil salinity and its associated effects on soil microorganisms, greenhouse gas emissions, crop yield, biodiversity and desertification: A review". *Science of the Total Environment*, 843, p.156946. 2022. doi: https://doi.org/10.1016/j.scitotenv.2022.156946

[14] N. Wang, S. Chen, J. Huang, F. Frappart, R. Taghizadeh, X. Zhang, J. P. Wigneron, J. Xue, Y. Xiao, J. Peng, and Z. Shi, "Global soil salinity estimation at 10 m using multi-source remote sensing," *Journal of Remote Sensing,* vol. 4, p. 0130, 2024. doi: https://doi.org/10.34133/remotesensing.0130

[15] C. Lekka, G. P. Petropoulos, D. Triantakonstantis, et al., "Exploring The Spatial Patterns Of Soil Salinity And Organic Carbon In Agricultural Areas Of Lesvos Island, Greece, Using Geoinformation Technologies," *Environ. Monit. Assess.,* vol. 195, p. 391, 2023. doi: https://doi.org/10.1007/s10661-023-10923-5

[16] F. Wang, L. Han, L. Liu, C. Bai, J. Ao, H. Hu, R. Li, X. Li, X. Guo, and Y. Wei, "Advancements and perspective in the quantitative assessment of soil salinity utilizing remote sensing and machine learning algorithms: A review," *Remote Sensing*, vol. 16, no. 24, p. 4812, 2024. doi: https://doi.org/10.3390/rs16244812

[17] A. Kumar, P. C. Moharana, R. K. Jena, S. K. Malyan, G. K. Sharma, R. K. Fagodiya, A. A. Shabnam, D. K. Jigyasu, K. M. V. Kumari, and S. G. Doss, "Digital mapping of soil organic carbon using machine learning algorithms in the upper Brahmaputra valley of northeastern India," *Land,* vol. 12, no. 10, p. 1841, 2023. doi: https://doi.org/10.3390/land12101841

[18] N. Mzid, O. Boussadia, R. Albrizio, A. M. Stellacci, M. Braham, and M. Todorovic, "Salinity properties retrieval from Sentinel-2 satellite data and machine learning algorithms," *Agronomy*, vol. 13, no. 3, p. 716, 2023. doi: https://doi.org/10.3390/agronomy13030716

[19] S. Kaliraj, K. Adhikari, S. Dharumarajan, M. Lalitha, and N. Kumar, "Chapter 3 -Remote sensing and geographic information system applications in mapping and assessment of soil resources," in *Remote Sensing of Soils*, Elsevier, 2024, pp. 25–41.doi: https://doi.org/10.1016/B978-0-443-18773-5.00014-4

[20] J. G. Kalambukattu, B. Johns, S. Kumar, A. D. Raj, and R. Ellur, "Temporal remote sensing based soil salinity mapping in Indo-Gangetic plain employing machine-learning techniques," *Proceedings of the Indian National Science Academy*, vol. 89, no. 2, pp. 290-305, 2023. doi https://doi.org/10.1007/s43538-023-00157-x

[21] J. Li, S. Wang, Y. Tang, Y. Du, L. Xu, J. Hu, and C. Zhu, "Coastal reclamation alters soil organic carbon dynamics: A meta-analysis in China," *Catena*, vol. 240, p. 107975, 2024. doi: https://doi.org/10.1016/j.catena.2024.107975

[22] B. Hossen, H. Yabar, and M. J. Faruque, "Exploring the potential of soil salinity assessment through remote sensing and GIS: Case study in the coastal rural areas of Bangladesh," *Land*, vol. 11, no. 10, p. 1784, 2022. doi: https://doi.org/10.3390/land11101784

[23] A. Qadeer, A. Wakeel, S. A. Cheema, T. Shahzad, and M. Sanaullah, "Integrated impacts of soil salinity and drought stresses on the decomposition of plant residues," *Sustainability*, vol. 16, no. 13, p. 5368, 2024. doi: https://doi.org/10.3390/su16135368

[24] H. M. Alkharabsheh, M. F. Seleiman, O. A. Hewedy, M. L. Battaglia, R. S. Jalal, B. A. Alhammad, C. Schillaci, N. Ali, and A. Al-Doss, "Field crop responses and management strategies to mitigate soil salinity in modern agriculture: A review," *Agronomy*, vol. 11, no. 11, p. 2299, 2021. doi: https://doi.org/10.3390/agronomy11112299

[25] S. Boubehziz, C. Piccini, M. A. Jiménez-González, and G. Almendros, "Spatial distribution of soil organic carbon quality descriptors

determining factors that affect its sequestration in Northeast Algeria," *Journal of Environmental Management*, vol. 358, p. 120772, 2024. doi: https://doi.org/10.1016/j.jenvman.2024.120772

[26] N. S. Kharrufa, "Simplified equation for evapotranspiration in arid regions," *Beitrage zur Hydrology*, no. 5, pp. 39–74, 1985.

[27] P. Buringh, "Soils and Soil Conditions of Iraq", Ministry of Agriculture, Agricultural Research and Projects, Baghdad, 1960.

[28] H. V. Dunnington, "Generation, migration, accumulation, and dissipation of oil in Northern Iraq," *GeoArabia,* vol. 10, no. 2, pp. 39-84, 2005, doi: https://doi.org/10.2113/geoarabia100239

[29] FAO (Food and Agriculture Organization of the United Nations), Agriculture Pest and Their Control Principles, Offset Press, Erbil, Iraq, 2000.

[30] S. N. Azeez, "Effects of some local conditions on leaching factor of aridisols in Kalar/Garmian, Kurdistan-Iraq," Kurdistan Journal of Applied Research (KJAR), vol. 1, no. 2, 2016. doi: https://doi.org/10.24017/science.2016.1.2.1

[31] F. H. Al-Taie, C. Sys, and G. Stoops, "Soil groups of Iraq, their classification and characteristics," Pedologie, no. 19, pp. 65-148, 1969.

[32] J. K. Kassim, K. Z. Al-Janabi, and M. I. Karim, "Soil temperature regimes in Iraq: II—Relationship between soil temperature and latitude, longitude, and elevation," Journal of Agriculture and Water Resources Research, vol. 8, no. 1, pp. 111–121, 1989.

[33] B. Markham, D. Jenstrom, B. Sauer, S. Pszcolka, V. Dulski, J. Hair, J. McCorkel, G. Kvaran, K. Thome, M. Montanaro, and J. Pedelty, et al., "Landsat 9 mission update and status," in *Earth Observing Systems* XXV, vol. 11501, pp. 96–102, SPIE, Aug. 2020. Doi: https://doi.org/10.1117/12.2569748

[34] S. M. Ahmad, "*Natural Map of the Kurdistan Region of Iraq",* Ministry of Higher Education and Scientific Research, Kurdistan Regional Government, Erbil, Iraq, 2005.

[35] L. A. Richards, "Diagnosis and Improvement of Saline and Alkali Soils", *Soil Science*, vol 78, no 2: p 154, August 1954. doi: http://dx.doi.org/10.1097/00010694-195408000-00012

[36] A. Walkley and I. A. Black, "An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method," *Soil Science*, vol. 37, no. 1, pp. 29–38, 1934.

[37] P. R. Hesse, *A Textbook of Soil Chemical Analysis*, London, UK: John Murray, 1971.

[38] W. Qu, J. Li, G. Han, *et al.*, "Effect of salinity on the decomposition of soil organic carbon in a tidal wetland," *Journal of Soils Sediments*, vol. 19, no. 2–3, pp. 609-617, 2019. doi: http://dx.doi.org/10.1007/s11368-018-2096-y

[39] H. Zubaidi, *Soil Salinity: Theoretical and Applied Principles*, Bait Al-Hekma, University of Baghdad, Baghdad, Iraq, 1989.

[40] S. N. Azeez, "Mapping of total lime using remote sensing and GIS technology, case study: Garmian District, Kurdistan Region-Iraq," *Passer Journal,* vol. 5, no. 2, pp. 243–248. 2023. doi: https://doi.org/10.24271/psr.2023.387488.1266

[41] M. R. Hadi and N. Karimi, "The role of calcium in plants salt tolerance," *Journal of Plant Nutrition*, vol. 35, no. 13, pp. 2037–2054, 2012. doi: https://doi.org/10.1080/01904167.2012.717158

[42] N. Gharaghanipor, A. Arzani, and M. Rahimmalek, "Physiological and transcriptome indicators of salt tolerance in wild and cultivated barley," *Frontiers in Plant Science*, vol. 13, 2022. doi: https://doi.org/10.3389/fpls.2022.819282

[43] P. Hoseinzadeh, B. Ruge-Wehling, P. Schweizer, N. Stein, and H. Pidon, "High-resolution mapping of a Hordeum bulbosum-derived powdery mildew resistance locus in barley using distinct homologous introgression lines," *Frontiers in Plant Science*, vol. 11, pp. 1–13, 2020. doi: https://doi.org/10.3389/fpls.2020.00225

[44] S. Taketa, H. Takahashi, and K. Takeda, "Genetic variation in barley of crossability with wheat and its quantitative trait loci analysis," *Euphytica*, vol. 103, no.2. pp. 187–193, 1998. doi: http://dx.doi.org/10.1023/A:1018344119747

[45] L. Zhang, R. A. Pickering and B. G. Murray, "Hordeum vulgare × H. bulbosum tetraploid hybrid provides useful agronomic introgression lines for breeders," *New Zealand Journal of Crop Horticultural Science*, vol. 29, no. 4, pp. 239–246, 2001. doi: https://doi.org/10.1080/01140671.2001.9514185

[46] A. H. Mohammed, J. I. Morrison, and B. S. Baldwin, "Preliminary screening of domestic barley and wild barley genotypes for salt tolerance," *Agrosystems, Geosciences & Environment*, vol. 4, no. 2, pp. 1–10, 2021. doi: https://doi.org/10.1002/agg2.20151

[47] B. Hailu and H. Mehari, "Impacts of soil salinity/sodicity on soil-water relations and plant growth in dry land areas: A review," J. Nat. Sci. Res, vol. 12, no. 3, pp. 1–10, 2021. doi: https://doi.org/10.7176/JNSR/12-3-01

[48] H. Akbarimoghaddam, M. Galavi, A. Ghanbari, and N. Panjehkeh, "Salinity effects on seed germination and seedling growth of bread wheat cultivars," *Trakia Journal of Sciences*, vol. 9, no. 1, pp. 43–50, 2011. ISSN 1313-7050 (print), ISSN 1313-3551 (online). https://www.researchgate.net/publication/215581915_Salinity_effects_on_seed_germination_and_seedling_growth_of_bread_wheat_cultivars

[49] Y. Waisel, "Biology of Halophytes", *Academic Press*, New York and London, 1972.

[50] V. N. Wong, R. S. Greene, B. W. Murphy, R. Dalal, S. Mann, and G. Farquhar, "The effects of salinity and sodicity on soil organic carbon stocks and fluxes: An overview," *in Regolith 2006: Consolidation and Dispersion of Ideas,* pp. 367–371.

[51] X. Chen, M. Luo, J. Tan, C. Zhang, Y. Liu, J. Huang, Y. Tan, L. Xiao, and Z. Xu, "Salt-tolerant plant moderates the effect of salinity on soil organic carbon mineralization in a subtropical tidal wetland," *Science of the Total Environment*, vol. 837, p. 155855, 2022. doi: https://doi.org/10.1016/j.scitotenv.2022.155855

[52] R. Setia, P. Gottschalk, P. Smith, P. Marschner, J. Baldock, D. Setia, and J. Smith, "Soil salinity decreases global soil organic carbon stocks," *Sci. Total Environ*., vol. 465, pp. 267-272, 2013. doi: https://doi.org/10.1016/j.scitotenv.2012.08.028

[53] S. Bandak, S. A. Movahedi-Naeini, S. Mehri, and A. Lotfata, "A longitudinal analysis of soil salinity changes using remotely sensed imageries," *Scientific Reports*, vol. 14, Article number: 10383, 2024. doi: https://doi.org/10.1038/s41598-024-60033-6

[54] F. Kaplan, "Detection of Soil Salinity Using Remote Sensing and Machine Learning: Innovative Approaches and Contributions," *MAS Journal of Applied Sciences,* vol. 10, no. 1, pp. 110–119, 2025. doi: http://dx.doi.org/10.5281/zenodo.15094133

[55] K. M. Gojiya, H. D. Rank, P. M. Chauhan, D. V. Patel, R. M. Satasiya, and G. V. Prajapati, "Remote sensing and GIS applications in soil salinity analysis: A comprehensive review," *Int. J. Environ. Clim. Chang*, vol. 13, issue 11. pp. 2149–2161, 2023.doi: https://doi.org/10.9734/ijecc/2023/v13i113377

[56] Y. Sui, R. Jiang, Y. Liu, X. Zhang, N. Lin, X. Zheng, B. Li, and H. Yu, "Predicting the spatial distribution of soil salinity based on multi-temporal multispectral images and environmental covariates," *Comput. Electron. Agric*., vol. 231, p.109970. 2025. doi: https://doi.org/10.1016/j.compag.2025.109970

[57] E. Asfaw, K. V. Suryabhagavan, and M. Argaw, "Soil salinity modeling and mapping using remote sensing and GIS: The case of Wonji sugar cane irrigation farm, Ethiopia," *J. Saudi Soc. Agric. Sci*., vol. 17, no. 3, pp. 250–258, 2018. doi: https://doi.org/10.1016/j.jssas.2016.05.003