

The Spatial Relationship between Soil Properties and the Manifestations of Desertification in Erbil Governorate and Their Effect on Agricultural Production (1995–2025)

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ABSTRACT

Desertification is one of the most serious contemporary environmental challenges, as degradation of soil properties (physical and chemical) reduces productive capacity and disrupts ecological balance. This study explores the spatial relationship between soil properties and desertification in Erbil Governorate during 1995–2025. Remote sensing and GIS were used, applying a Multi-Criteria Evaluation (MCE) model via Model Builder. Five main factors were evaluated: precipitation rate, temperature, soil type, slope, and vegetation density. These factors were integrated using the Weighted Overlay tool to identify areas at risk of desertification. The results revealed clear spatial variation. The northern and eastern areas are more resistant to desertification due to the high moisture and organic matter content of their soils. Conversely, the undulating southern area suffers from moderate to severe desertification due to high salinity and weak soil structure. Areas with moderate desertification account for approximately 45.60% of the governorate, while areas with severe desertification account for 16.0%, showing a sharp decline in agricultural production. Human factors, including poor management, excessive irrigation, and urban expansion, have interacted with climatic factors, specifically drought and rising temperatures, to exacerbate the phenomenon, threatening the region's economic development. The study confirms the effectiveness of GIS techniques in accurately monitoring desertification dynamics, underlining the need to adopt them as an essential instrument for sustainable environmental management plans and for protecting food security in the governorate.

KEYWORDS: Desertification, Soil properties, Land degradation, Agricultural Production, Remote sensing.

1. ¹INTRODUCTION

Soil is one of the most significant natural resources upon which plant life and agriculture depend, and it represents a central pillar for achieving food security and sustainable development. It is the biological medium in which physical, chemical, and biological processes interact to provide plants with essential nutrients, making it a principal indicator of land fertility and agricultural productivity. However, soil in Erbil

Governorate, like many other areas of Iraq, has been exposed in recent decades to distinct forms of environmental degradation resulting from natural and human factors, foremost among which is desertification. Desertification has become an environmental, economic, and social problem that threatens agricultural production potential and the balance of the local ecosystem. Desertification is thoroughly associated with soil properties, as any alteration in its physical components, such as texture, permeability, and bulk density, or in its chemical properties, such as salinity and salt accumulation, leads to a decline in its productive capacity and loss of fertility. Therefore, contributing to the expansion of desertified areas and the decline of natural and agricultural vegetation cover. In addition, the overexploitation of agricultural land, excessive grazing, and deprived management of water resources have exacerbated problems of soil erosion, degradation, and deterioration of soil structure in various areas of Erbil. This spatial relationship between

¹. Koya University Journal of Humanities and Social Sciences (KUJHSS) Volume 9, Issue 2, 2026.

Received 30 May 2025;

Accepted 7 September 2026

Regular research paper: Published 28 September 2026

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soil properties and the manifestations of desertification highlights the vitality of investigating the spatial distribution of soil types and their properties in Erbil Governorate and examining their direct effect on land degradation and agricultural production during the period 1995–2025. This study contributes to comprehending the dynamics of spatial and temporal changes in soil and the extent of its vulnerability to climatic and human factors, consequently supporting the preparation of digital maps that identify areas of environmental risk and assist organizers and decision-makers in developing strategies to combat desertification and preserve soil as an important and renewable resource.

2. RESEARCH PROBLEM

The research problem lies in the continuous deterioration of the physical and chemical properties of soil in Erbil Governorate, accompanied through the expansion of desertification manifestations and a decline in agricultural production over the past three decades. Field observations and satellite imagery specify clear spatial and temporal changes in soil conditions, including increased salinity, a decline in organic substance, the disintegration of soil structure, as well as inadequate management of land and water resources. Collectively, these phenomena have resulted in an imbalance in the agricultural ecological system and a decline in soil fertility and agricultural productivity, raising questions about the nature of the spatial relationship between soil properties and the manifestations of desertification in the governorate.

Research Hypothesis

The study hypothesizes that there is an inverse relationship between soil fertility and desertification and between soil fertility and the spread of desertification manifestations in Erbil Governorate. The severity of desertification is expected to increase with increasing soil salinity, declining fertility, and the disintegration of soil structure, resulting in a spatial decline in agricultural production over time. It is also hypothesized that spatial variations in soil properties among the districts of the governorate contribute to differences in their degrees of vulnerability to desertification.

The significance of the Study

The significance of this study is attained to establish the link the spatial analysis of soil with the problematic issue of desertification and agricultural production throughout the use of modern scientific instruments, such as satellite imagery analysis and Geographic

Information Systems (GIS). This approach enables the accurate identification of areas of degradation and the assessment of levels of environmental risk. The results are also expected to support sustainable agricultural expansion plans in Erbil Governorate, guide efforts toward more effective management of natural resources, and reduce the hazards of desertification through the adoption of scientifically informed policies for land use and soil conservation.

Research Objectives

The study aims to analyze the spatial relationship between soil properties and the manifestations of desertification in Erbil Governorate and their impact on agricultural production during the period (1995–2025), through the following:

1. Identifying the physical and chemical properties of soil in the study areas.
2. Examining the spatial and temporal changes in the manifestations of desertification.
2. Measuring the degree of reciprocal influence among soil, desertification, and agricultural production.
3. Formulating spatial maps demonstrating areas of environmental degradation and desertification risks in the governorate.

Research Methodology

The study adopted descriptive and experimental approaches. The descriptive approach focused on the historical dimension and the geographical and environmental characteristics of the study area, while the temporal sequence of the period under investigation required comparison of the details of the phenomenon and geographical surveying of the area. The experimental approach focused on examining the relationships among the factors in order to clarify the geographical dimensions and define the degree of influence of the factors investigated in the study. This approach involved quantitative analysis using numerical data, mathematical equations, and modern mathematical models.

Spatial Boundaries of the Study Area

Erbil Governorate is located in the northern part of Iraq. It is bordered by Kirkuk Governorate to the south, Nineveh and Duhok Governorates to the west, and Sulaymaniyah Governorate and the Islamic Republic of Iran to the east. To the north, it shares part of Iraq's international political boundary with Türkiye (General Authority for Meteorology and Seismic Monitoring, 2025, pp. 4–5).

The astronomical location of the governorate is approximately between latitudes 35°05' and 37°25' N and longitudes 43°25' and 45°25' E, as shown in Map (1).

The governorate covers an area of approximately 14,168.5 km², equivalent to about 3.25% of the total area

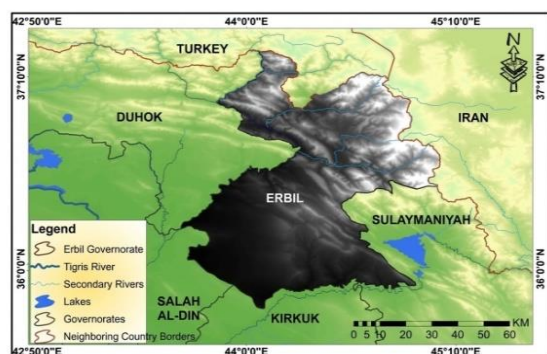
of Iraq, which quantities to 437,072 km² (Central Statistical Organization – General Authority for Statistics and Geographic Information Systems, Statistical Abstract of Iraq – Area of Iraq, p. 12).

The governorate comprises 40 administrative subdistricts (Nawahi) distributed among 10 districts (Aqdas), namely Mergasor, Soran, Choman, Rawanduz, Shaqlawa, Khebat, Erbil, Deshti-Hawler, Koysinjaq, and Mekhmur.

Erbil Governorate was nominated as the study area due to the importance of geographical location and the diversity of geographical characteristics, particularly natural features. These comprise diverse geological formations and varied topographical units that range from extensive flat plains to undulating and narrow plains, followed by mountainous valleys and slopes ranging from moderate to steep gradients. Furthermore, the governorate exhibits an evident variation in the climatic elements, particularly temperature and precipitation, as well as considerable diversity in vegetation regions.

Temporal Boundaries of the Study

The study relied on data issued by the Ministry of Agriculture of the Kurdistan Region, specifically the Directorate of Agriculture of Erbil Governorate, covering the period from 1995 to 2025.



Map 1

Source: Prepared by the researcher based on the General Directorate of Survey, Administrative Map of Iraq, scale 1:1,000,000, 2025; Directorate of Agriculture of Erbil Governorate, GIS Division, Map of Erbil Governorate; and the Digital Elevation Model (DEM) of Erbil Governorate, generated using ArcGIS 10.8.

Key Concept and Terminology Related to the Study

1. Desertification

Desertification is the process of land degradation in dry, semi-dry, arid, semi-arid, and semi-humid areas resulting from the interaction of natural and human factors. It leads to a decline in the biological and economic productivity of soil and ecosystems (United Nations Environment Programme, 2019, p. 142). Desertification is considered one of the most serious global environmental problems because results in the loss of vegetation cover, soil erosion, and declining land

fertility, thereby threatening food security and sustainable development (United Nations Economic and Social Commission for Western Asia [ESCWA], 2020, pp. 28–30).

2. Spatial Relationship

Spatial relationship is a geographical concept referring to the interconnectedness or interaction among phenomena within a particular space; that is, how elements such as population, resources, soil, and water are distributed across the geographical space and how they influence one another (Hassan, 2018, p. 94). Spatial relationships establish a fundamental basis for analyzing geographical patterns, such as the relationship between desertification and soil characteristics, climate, or human activities (Yousif, 2017, pp. 115–118).

3. Environmental Degradation

Environmental degradation refers to the negative changes affecting the components of the natural environment as a result of excessive human activities or natural processes, leading to the loss of ecological balance and a decline in quality of life (Al-Samarrai, 2021, p. 63). Its manifestations involve air and water pollution, deforestation, erosion, desertification, and biodiversity loss (World Bank, 2022, p. 47). Environmental degradation is considered an indicator of unsustainable use of natural resources (General Authority for Meteorology and Seismic Monitoring – Ministry of Transport and Communications, 2025).

Section one: Geographical Characteristics Causing Desertification in Erbil Governorate During the Period (1995-2025).

First: Natural Characteristics

1. Geology And Rock Formations In Erbil Governorate

The geological characteristics and rock formations of Erbil Governorate are among the principal factors controlling the nature and spatial distribution of soils and, consequently, the manifestations of desertification and the level of agricultural production. The nature of rocks and their mechanical and mineral characteristics influence soil formation, depth, permeability, organic matter content, and the availability of nutrients for plants. These factors directly affect the level of fertility of agricultural lands and their productive capacity (Jassim & Badri, 2020, p. 58).

Erbil Governorate contains a variety of geological formations, most notably the Qamchuqa Formation, Aqra-Bekhme Formation, and Kirkuk Formation, in addition to other sedimentary formations dating to the Miocene and Cretaceous periods (Al-Kubaisi & Al-Samarraie, 2019, p. 53). These formations range from hard limestone and dolomitic rocks in mountainous areas to relatively unconsolidated sedimentary rocks in plain and semi-mountainous areas. This variation results in considerable diversity in soil characteristics. Soils

developed over limestone rocks are generally shallow and poor in organic matter, whereas soils formed over sedimentary rocks tend to be relatively deeper and more fertile, making them more suitable for agricultural activities (Buday & Jassim, 1987, p. 210).

The widespread distribution of calcareous rocks across large areas of the governorate also makes some soil types rich in calcium and magnesium salts. These elements may limit the ability of plants to absorb certain micronutrients, thereby affecting plant growth and agricultural production, particularly in the southern and western areas of Erbil (Kurdistan Region, NE Iraq, pp. 29–52). On the other hand, clayey and sandy formations in the plain areas contribute to increasing soil permeability and improving its physical properties, which positively affects agricultural production.

The geological variation in Erbil Governorate also contributes to differences in the degree of soil susceptibility to desertification. Areas characterized by hard, fractured rocks and a weak soil cover are more vulnerable to erosion, including water and wind erosion. This leads to the degradation of vegetation cover and an increase in desertification manifestations. In contrast, areas characterized by soft sedimentary rocks and deep soils have a greater capacity to retain moisture and nutrients, which reduces the severity of desertification and promotes sustainable agricultural production.

Accordingly, the geological structure and rock formations of Erbil Governorate constitute the geomorphological foundation that helps explain the spatial relationship among soil properties, desertification manifestations, and agricultural production. Differences in the nature of the underlying rocks are reflected in variations in soil type and fertility and, consequently, in agricultural production levels within an environment characterized by considerable topographical and climatic variation.

2. Surface Topography in Erbil Governorate

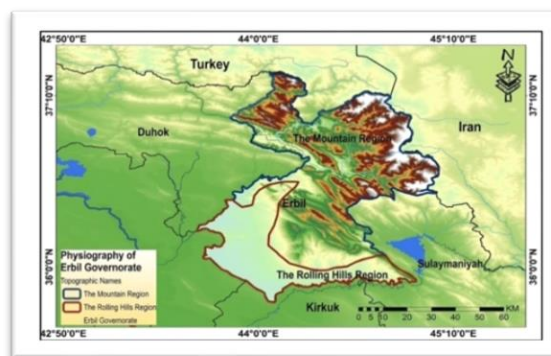
According to Map (2) and Table (1), the topography of Erbil Governorate exhibits clear variation between two main areas: the mountainous area, which covers approximately 58.96% of the total area; and the undulating area, which represents approximately 22.63% of the governorate's area. The remaining 18.41% consists of plains and depressions.

This topographical variation is a determining factor in the spatial distribution of soil properties and the intensity of desertification manifestations in the governorate, as slope and surface configuration are directly associated with erosion processes, soil loss, and declining fertility. In the mountainous area, steep slopes predominate, accelerating surface-water runoff and intensifying water erosion. This negatively affects the stability of vegetation cover and increases soil susceptibility to desertification (Buday & Jassim, 1987, p.

215). The soils of these areas are also characterized by shallow depths and low organic matter content as a result of continuous erosion processes (University of Baghdad Press, p. 112).

In contrast, the undulating area located in the south is relatively more suitable for agricultural activities, as it is characterized by moderate slopes and relatively deeper soils. Consequently, it represents a major area for agricultural land use, particularly for cereal cultivation and field crops (Knutson & Al-Ansari, 2011, pp. 53–67). However, its continued exposure to drought and fluctuations in precipitation during the period 1995–2025 has contributed to a decline in agricultural production and an increase in desertification manifestations, such as salinization, soil hardening, and loss of organic matter.

Accordingly, the spatial relationship among surface topography, soil properties, and desertification manifestations in Erbil Governorate indicates that areas with steep slopes constitute environmentally sensitive areas that are more vulnerable to soil degradation. In contrast, the undulating areas represent the primary agricultural domain but face the risk of advancing desertification as a result of climatic changes and unsustainable human activities.



Map 2

Topography of Sinai Governorate

Source: Researcher, based on data from the Ministry of Industry and Minerals and GIS ArcGIS 10.8 software, scale 1:250,000

Table 1

Areas and Percentages of Topographic Divisions in Sinai Governorate

No	Topographic Region	Area(km ²)	Percentage (%)
1	Mountainous Area	8.3551	58.96
2	Plain Area	3.2043	22.63
3	Plains and Depressions	2.6091	18.41
	Total	14.168.5	100

Source: Prepared by the researcher based on Map (2).

Map (3), which represents the slope and topographic aspect (Aspect), shows that the surface of the governorate varies between flat areas and slopes with different orientations. The flat areas (value –1) represent

plains and low-lying depressions where rainwater and floodwaters accumulate. These areas are characterized by relatively deep soils. This indicates that areas within this category receive greater amounts of solar radiation and accumulated heat, resulting in soils with lower moisture content and greater susceptibility to disintegration. This plays a significant role in intensifying weathering and erosion processes in all their forms, producing loose surfaces that are easily eroded and transported by watercourses. It also affects the activity and nature of the prevailing morphoclimatic processes. These lands are considered among the principal agricultural areas when proper water management is available.

The northern and northeastern slopes (0–67.5°) receive relatively lower levels of direct solar radiation and retain comparatively higher levels of moisture, making them more suitable for the growth of perennial vegetation and natural pastures. The soils in these areas are also generally more stable and less susceptible to erosion. Consequently, these areas represent promising locations for reforestation and the improvement of vegetation cover as part of desertification-control efforts.

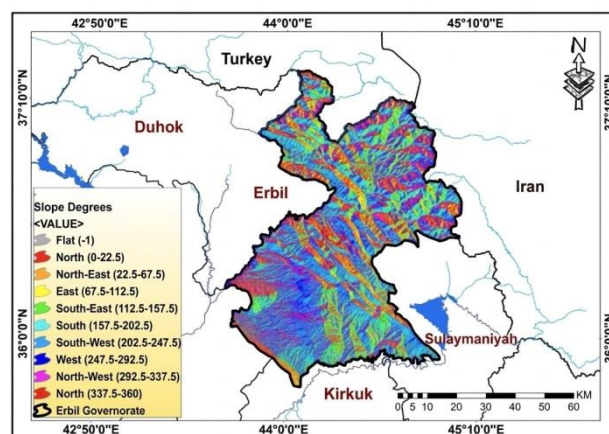
In contrast, the southern and southwestern slopes (157.5–247.5°) experience the highest levels of exposure to solar radiation, which increases temperatures and soil-moisture loss and contributes to accelerating erosion processes, including water and wind erosion, particularly in mountainous areas characterized by steep slopes. This has negatively affected soil fertility and the stability of vegetation cover during the period 1995–2025. A clear increase in desertification manifestations has been observed, including soil erosion, surface hardening, and declining organic matter content, resulting in decreased agricultural production in these areas, particularly for rain-fed field crops.

The eastern and western slopes represent intermediate conditions in terms of solar exposure and moisture. Eastern slopes receive solar radiation during the early morning hours, providing moderate warmth and relatively balanced agricultural conditions, whereas western slopes are exposed to higher temperatures during the afternoon and evening, increasing heat stress on plants and affecting the soil's capacity to retain moisture.

The distribution of slope degrees and surface aspects in Erbil Governorate clearly demonstrates that topography is an influential factor in the variation of soil properties and desertification manifestations. Soil susceptibility to degradation increases with greater slope gradients and with surface orientations toward the south and west, whereas soil fertility and stability tend to increase toward the north and northeast. These factors, together with climatic changes and fluctuations in precipitation during the last three decades, have

contributed to differences in agricultural production levels across the governorate. The northern and northeastern areas have remained relatively more environmentally and agriculturally stable, whereas the southern and western areas have experienced a noticeable decline in production and an expansion of desertified areas.

Accordingly, slope gradients and surface aspects can be regarded as two key factors for understanding the spatial relationship among soil properties, desertification manifestations, and agricultural production in Erbil Governorate. This necessitates directing sustainable management plans toward areas that are more vulnerable to degradation through soil stabilization, improvement of vegetation cover, and the application of water-harvesting techniques to ensure the conservation of land resources and reduce future desertification risks.



Map 3

Slope Degrees in Erbil Governorate

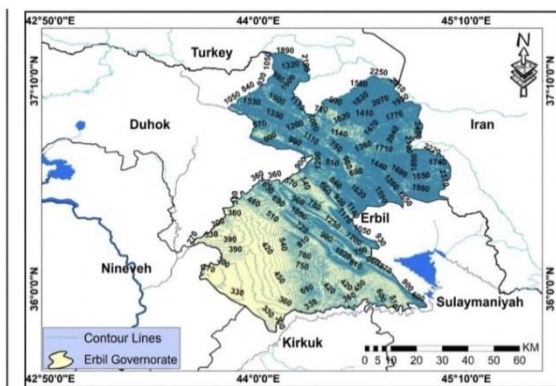
Source: Prepared by the researcher based on the Digital Elevation Model (DEM) of Erbil Governorate and the outputs of ArcGIS 10.8.

Map (4) shows the contour lines of elevation in Erbil Governorate, which exhibit considerable topographic variation reflecting the transitional geographical location of the governorate between the rugged northern mountainous ranges and the relatively level southern plains. The elevation values shown on the map, ranging from 270 m in the lowest areas to 2,490 m in the highest areas, constitute one of the major factors explaining the distribution of soils, the intensity of desertification manifestations, and patterns of agricultural activity during the period 1995–2025.

The map indicates that the contour lines are highly concentrated in the northern, eastern, and western parts of the governorate, particularly along the borders with Türkiye and Iran. This indicates the presence of steep mountainous terrain, including the Handrin, Sefin, and Bradost ranges and the slopes of Mount Korek, where elevations range from 1,500 to 2,490 m above sea level.

These areas are characterized by steep slopes and thin soils with low organic matter content. They are also strongly affected by erosion and surface runoff, making them environmentally fragile areas that are more vulnerable to manifestations of mountainous desertification, particularly the degradation of natural vegetation cover and the formation of exposed rocky surfaces.

The central region of the governorate, including the city of Erbil and surrounding areas, has elevations ranging between 700 and 1,200 m, which represents a transitional zone between the mountainous highlands to the north and the undulating areas to the south. These areas are characterized by moderate slopes and soils of medium depth, which are often formed from weathered and transported mountain sediments that relatively suitable for rain-fed agriculture when sufficient precipitation is available; however, they remain vulnerable to drought and salinization during dry seasons.



Map 4

Elevation Contour Lines in Sinai Governorate

Source: Researcher, based on Digital Elevation Model (DEM) of Sinai Governorate using ArcGIS 10.8 software

3. Climate in Erbil Governorate

Climate is one of the principal natural factors manipulating the formation of soil properties and the development of desertification manifestations in Erbil Governorate. The main elements are temperature, precipitation, wind, and relative humidity that exert a direct influence on the geomorphological and environmental processes that determine soil fertility and productive capacity (Climatic Water Balance at the Stations of Erbil and Anbar Governorates in Iraq for the Period "1981–2010," 2019, pp. 412–415). Spatial and temporal variations in these elements are clearly reflected in the nature of vegetation cover and the level of soil moisture and, consequently, in the intensity of the prevailing desertification manifestations across the governorate.

The climatic data from Erbil Station for the period (1995–2025), the details of which are presented in Table (2), indicate that the governorate experiences a semi-arid

Mediterranean climate characterized by hot, dry summers and cold, rainy winters, with obvious variations in temperature among the seasons. The annual mean temperature reached approximately 20.5°C, rising to about 41.6°C in July, while decreasing to approximately 4.8°C in January. This considerable thermal variation contributes to increasing the rates of physical weathering of rocks, thereby weakening the cohesion of their particles and accelerating erosion and soil-loss processes. Table (3) shows the climatic characteristics of Erbil Station during the period (1995–2025), indicating the close relationship between climatic elements and changes in soil properties and desertification manifestations in the governorate. Increased temperatures, low precipitation, and higher evaporation rates accelerate erosion processes and the loss of organic matter from the soil, leading to declining fertility and reduced agricultural production efficiency. Precipitation is symbolized by a distinct seasonal distribution, with an annual average of approximately 658.2 mm and concentrated mainly during the winter season, particularly in January and February, while it is almost completely absent during the summer months (July–August). This irregular distribution results in fluctuations in soil moisture, as the soil undergoes drying and hardening during summer and subsequently experiences cracking and erosion during periods of heavy rainfall. This is considered one of the most prominent manifestations of actual desertification in the region.

Wind is also one of the climatic elements influencing the dynamics of the Earth's surface. This annual mean speed reached approximately 2.1 m/s, which is predominantly northwesterly. These winds contribute to increasing evaporation rates during summer and transporting loose soil particles in exposed and dry areas, resulting in the degradation of the fertile surface layer of the soil and increased rates of wind erosion. Relative humidity, meanwhile, recorded an annual average of approximately 48%, with clear seasonal variation. It increased to approximately 70% during winter and decreased to less than 30% during summer, thereby intensifying soil dryness in summer and limiting its capacity to support natural vegetation cover.

Accordingly, the climate of Erbil Governorate can be regarded as one of the principal environmental determinants explaining the spatial variation in soil properties and desertification manifestations. This condition of climate contributes directly to determining the quality of agricultural lands and their productive capacity and represents a key factor in shaping the relationship between the natural environment and the sustainability of agricultural development in the governorate.

Table 2
Climatic Characteristics of Erbil Station in the Study Area

The Station	X/ Longitude	Y/ Latitude	Elevation Above Sea Level (m)
Erbil Station	36°12'	44°04'	435

Source: Prepared by the researcher based on the General Authority for Iraqi Meteorology, Ministry of Transport and Communications, Baghdad, unpublished data, Erbil Governorate, 2025.

Table 3
Climatic Data of Erbil Station for the Period (1995–2025)

The month	Maximum Temperatures	Minimum Temperatures	Overall average temperature	Average wind speed	Total rainfall	Relative humidity
January	10.2	4.8	7.5	2.0	130.3	70
February	13.4	6.1	9.7	2.1	116.5	67
March	18.9	9.2	14.0	2.0	110.4	62
April	24.6	13.3	18.9	2.1	81.2	55
May	31.7	18.2	24.9	2.2	49.6	45
June	37.5	22.7	30.1	2.3	1.5	35
July	41.6	25.8	33.7	2.1	0.0	28
August	41.2	25.3	33.2	2.1	0.0	29
September	36.9	21.1	29.0	2.0	3.1	35
October	29.1	15.7	22.4	2.0	46.4	48
November	19.4	9.3	14.3	2.1	67.2	60
December	12.1	5.6	8.8	2.0	52.0	68
Average Annual Total	26.5	14.6	20.5	2.1	658.2	48

Source: Prepared by the researcher based on the Ministry of Transport, General Authority for Meteorology and Seismic Monitoring, Climate Department, unpublished data (2025).

4. Soil and Its Properties in Erbil Governorate

Soil is one of the principal natural elements determining the level of agricultural production in any region, as represents the biological medium in which plants grow. The properties are directly influenced by geological, climatic, and human factors (Ali Mohammed, 2018, p. 126). In Erbil Governorate, soils vary in terms of their depth, texture, organic-matter content, salinity, and alkalinity as a result of variations in topography, ranging from extensive plains to mountainous highlands, in addition to differences in precipitation, temperature, and vegetation cover. The soils of the northern and central plains consist mainly of silt and clay materials transported by watercourses from the adjacent highlands. Consequently, they are deep, fine-

textured soils with high fertility and moderate permeability, making them suitable for the cultivation of cereals, legumes, and vegetables. Contrastively, shallow calcareous and sandy soils predominate in the mountainous and semi-arid areas located in the southwestern part of the governorate (Fadhil, 2020, p. 45). These soils are characterized by weak cohesion and low organic-matter content, making them vulnerable to water and wind erosion and reducing their capacity to retain moisture, thereby resulting in lower agricultural productivity.

Field studies indicate that soil thickness in areas with steep slopes does not exceed 40–60 cm, whereas increasing in flat areas and floodplains to more than two metres. Soil permeability also ranges from slow in silty and clayey soils to rapid in sandy soils. This variation results in explicit differences in surface-runoff and water-infiltration rates across different parts of the governorate. Organic-matter content ranges between 1% and 3% (Rashid, 2019, pp. 22–24), depending on vegetation-cover density and soil depth which is one of the critical factors contributing to resistance to erosion and improving soil structure. While, some areas of Erbil, particularly the southern and western parts, suffer from increasing soil salinity and hardening as a result of high groundwater levels and poor irrigation management (Salim, 2021, p. 89), in addition to fluctuations in precipitation during the period (1995–2025). This change has resulted in deterioration of natural fertility and a decline in the productivity of agricultural lands, particularly in major crops such as barley and wheat. Furthermore, the decline in organic matter and the disintegration of soil structure have contributed to increasing rates of surface erosion, which is directly associated with manifestations of desertification in the region.

Map (5) illustrates the soil types in Erbil Governorate, as follows:

A. Chromoxererts Soil (Chromoxererts)

Chromoxererts soil is one of the most widely distributed soil types in the Erbil Plain and the central areas of the governorate that categorized through the dark color and high content of clay that undergoes expansion and contraction depending on moisture conditions (Ali Raed, 2022, p. 104). These properties produce a high productive capacity under proper agricultural management. However, the sensitivity is clear among most soils to degradation when subjected to excessive ploughing or insufficient vegetation cover, as the surface layer rapidly becomes hardened and vulnerable to water and wind erosion. In addition, poor drainage in some locations contributes to increasing salinity, which negatively affects soil fertility and agricultural productivity. Therefore, this soil represents an agricultural environment with considerable

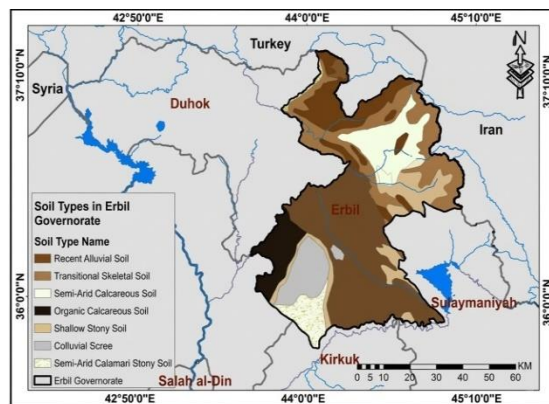
productive potential, but it is threatened by desertification in cases of improper utilization.

B. Chromoxererts-Shallow Phase

This soil is distributed in the transitional areas between the plains and the northern, northeastern, and western slopes of Erbil which characterized by limited depth and the presence of bedrock at shallow depths (Fadhil, 2021, p. 31). This condition reduces the soil capacity to retain moisture and nutrients, thereby limiting its agricultural productivity. This action becomes a direct exposure to water erosion during winter and wind erosion during summer also accelerates desertification manifestations. Accordingly, this type of soil indicates a transitional stage between productive lands and degraded lands and constitutes a clear indicator of declining vegetation cover and intensifying erosion in the governorate.

C. Lithic Calciorthids, Eroded Phase

This soil occurs on mountain foothills and semi-mountainous areas, particularly in northeastern Erbil Governorate that has a light-textured calcareous soil affected by slope conditions and water erosion. This type characterized by low organic-matter content and a high proportion of calcium carbonate, which provides a limited fertility and weak water-retention capacity. These properties of the soil reaches to the feature of highly susceptible to desertification (Sami, 2020, p. 78), particularly under conditions of overgrazing or unstable rain-fed agriculture. Over time, the degree of degradation increases, reducing its capacity to support any sustainable agricultural activity.



Map 5

Types of Soils in Erbil Governorate

Source: Prepared by the researcher based on P. Buring (1960), Soils and Soil Conditions in Iraq (Ministry of Agriculture, Baghdad), and the outputs of ArcMap 10.8.

A. Recent Alluvial Soil

Mollic Calciorthids soil is considered a moderately fertile soil and is distributed across the southern and southeastern parts of Erbil Governorate that characterized by a dark colour, moderate organic-matter content, and a relatively balanced proportion of sand

and clay. When water is available and proper drainage management is ensured, becomes more suitable for the cultivation of cereals and vegetables. However, excessive use of chemical fertilizers and irregular irrigation contribute to increasing the salinity and hardening the surface layers, making it vulnerable to gradual degradation and a progressive decline in agricultural production, particularly during dry seasons (Ali Mohammed, 2018, p. 130).

B. Shallow Transitional Soil

This soil is distributed along the northern mountain foothills of Erbil and is characterized by its shallow depth and direct contact with the underlying bedrock. This type contains low proportions of organic matter and is covered by sparse or discontinuous vegetation. Consequently, this kind of soil among the other types most vulnerable to erosion and soil loss, whether water erosion during the rainy season or wind erosion during dry periods and limited depth also reduces the agricultural productivity and becomes suitable mainly for seasonal grazing. These areas are considered among the most environmentally fragile environments within the governorate and constitute a clear indicator of the severity of desertification in mountainous environments (Fadhil, 2020, p. 38).

C. Shallow Lithic Soil

These areas occur on steep slopes and rocky highlands and are virtually devoid of agricultural soil. They are covered by layers of fragmented rock debris resulting from weathering and slope processes. These areas function as groundwater recharge zones but have virtually no agricultural productivity, as they can be utilized for agriculture or grazing only to a very limited extent. Nevertheless, they constitute a source of eroded materials that are transported toward low-lying lands, thereby contributing to the degradation of adjacent soils and the expansion of desertification manifestations (Rashid, 2019, p. 27).

D. Rock-Debris Soil

This soil is distributed across the upper northeastern highlands and is subjected to harsh climatic conditions characterized by low temperatures, heavy winter precipitation, and snow accumulation. This kind of soil cover is extremely shallow and poorly developed, with sparse and discontinuous natural vegetation. These characteristics of the soil represents it as unsuitable for agriculture, while the continuous exposure to erosion and slope processes results in the gradual loss of the soil cover. Therefore, these areas are considered among the most fragile environments in Erbil Governorate and clearly represent the most advanced stages of natural and geographical desertification in the mountainous environment (Sami, 2020, p. 82).

The soils of Erbil Governorate exhibit considerable variation in their physical, chemical, and biological

properties according to differences in geomorphological and climatic factors and land-use patterns (Journal of Earth Sciences, 2018, pp. 15-17). From a physical perspective, soils vary in terms of depth, texture, and structure. In the central and eastern plains, soils are characterized by considerable depth, ranging between 1 and 2 m, with a moderately structured silty-clay texture and medium permeability that allows water to be stored and utilized for irrigated agriculture, making these soils more suitable for stable agricultural production (Ministry of Agriculture and Water Resources – Kurdistan Region, 2020, p. 11). In contrast, shallow soils predominate in the mountainous and semi-arid areas in the southern and western parts of the governorate. Their depth does not exceed 40-60 cm, and they generally have a sandy or light calcareous texture, weak cohesion, and high permeability. These characteristics reduce their capacity to retain moisture and increase their vulnerability to water and wind erosion. Bulk density ranges between 1.2 and 1.6 g/cm³, depending on organic-matter content and the proportion of clay. Porosity decreases in hardened or compacted soils, whereas shrink-swell potential increases in soils rich in expansive clay, causing them to crack during periods of drought and resulting in the loss of the fertile surface layer.

From a chemical perspective, the soils of Erbil are affected by climatic conditions, the nature of the parent rock, and agricultural activities. Soil pH values range between 7.3 and 8.4, indicating a slightly to moderately alkaline character resulting from the high proportions of calcium carbonate associated with the widespread distribution of limestone rocks within the Zagros region. Total salinity, measured by electrical conductivity (EC), varies spatially that increases in the southern and western areas due to high groundwater levels and poor agricultural drainage, reaching more than 6 dS/m, whereas it remains within acceptable limits in the northern and central plains. Organic-matter content is relatively low, ranging between only 1% and 3%, reflecting sparse vegetation cover and high rates of oxidation under the semi-arid climate. Concentrations of nutrients such as phosphorus and potassium also vary between cultivated areas, where concentrations are relatively high, and rain-fed or desertified areas, where values are low. This variation demonstrates the influence of agricultural activity and climate on soil fertility. Increased salinity in some areas leads to reduced permeability and hardening of the surface layer, whereas the accumulation of calcium carbonate contributes to soil calcification and obstructs root growth and nutrient uptake. These conditions represent clear manifestations of soil degradation and desertification.

The biological properties of the soils generally indicate weak biological activity as a result of drought, high summer temperatures, and the scarcity of vegetation cover across most areas, particularly mountainous and dry regions. Reduced microbial activity leads to a decline in organic decomposition and humus formation, thereby weakening soil structure and reducing its capacity to retain nutrients. The populations of beneficial microorganisms, such as nitrogen-fixing bacteria and decomposer fungi, also decline in saline or poorly drained soils. Nevertheless, some areas of the northeastern plains retain a certain level of biological activity due to soil moisture and the diversity of seasonal herbaceous vegetation, which provides them with greater capacity to resist environmental degradation and desertification (Environmental Studies Center, University of Erbil, 2021, p. 54).

In general, the soils of Erbil Governorate exhibit clear spatial variation in their properties. Deep and fertile soils in the plains are more productive and stable, whereas shallow soils on slopes and in arid areas undergo degradation as a result of erosion, salinity, and calcification, placing them among the areas at risk of desertification. Accordingly, understanding these physical, chemical, and biological properties constitutes an essential scientific basis for interpreting the spatial relationship between soil and desertification manifestations and for developing sustainable management strategies to improve agricultural production and maintain environmental balance in Erbil Governorate.

5. Surface and Groundwater

Surface and groundwater play an important role in determining the degree of desertification and the level of agricultural production in Erbil Governorate, as they constitute major environmental elements affecting soil properties and the water balance. Surface water resulting from rainfall or runoff contributes to soil moisture and enhances its productive capacity. Moreover, regularity in its temporal and spatial distribution limits the degradation of vegetation cover and reduces manifestations of drought and desertification. During dry years, when precipitation rates decline, the reduction in surface moisture leads to soil hardening, declining fertility, and increased rates of wind and water erosion. Groundwater, meanwhile, plays a complementary role in supporting agricultural activity, as farmers in large parts of the governorate depend on it to irrigate crops during periods of rainfall interruption (Ali, 2019, pp. 110-112). However, excessive exploitation without sufficient natural recharge results in declining groundwater levels and the salinization of some agricultural lands, thereby contributing to the expansion of desertified areas. Consequently, achieving a balance between the use of surface and groundwater

resources is an essential condition for maintaining soil fertility and ensuring sustainable agricultural production in Erbil Governorate.

6. Vegetation Cover in Erbil Governorate

Vegetation cover is one of the fundamental environmental elements that directly affects soil properties, the level of desertification, and agricultural production in Erbil Governorate. The denser and more continuous the vegetation cover, the more effectively it contributes to stabilizing the soil and limiting the erosion by wind and rainfall and also increases the soil's capacity to retain moisture and maintains its organic and mineral balance (Hussein, 2017, pp. 205–218). Plant roots play an effective role in binding soil particles and preventing their disintegration, thereby reducing erosion, limiting the expansion of desertified areas, and consequently increasing the efficiency and productivity of agricultural lands.

Vegetation cover is unevenly distributed across Erbil Governorate according to variations in topography, climate, and soil type. Vegetation density varies between the northern mountainous regions, which receive abundant rainfall, and the semi-arid regions in the south and west. The northern and eastern highlands, particularly the areas of Pirmam, Harir, Qush Tapa, and Bibiān, are characterized by natural and artificial forests containing species of oak, deciduous trees, and seasonal grasses. Map (1-6) aims to monitor and identify the extent and spatial distribution of vegetation cover in the study area (Erbil Governorate) by employing the area-gradient method and color shading based on the Normalized Difference Vegetation Index (NDVI), according to the classification of Lioa (1999, p. 24).

The results divided the study area into four principal categories:

1. Barren lands and low-density vegetation:

This category ranked first, covering an area of 9,707.2 km², equivalent to 65.3% of the total area that covers extensive parts of the plains and the southern and southwestern areas.

2. Medium-density vegetation:

This category ranked second, covering an area of 2,197.2 km², accounting for 14.7% of the governorate's total area.

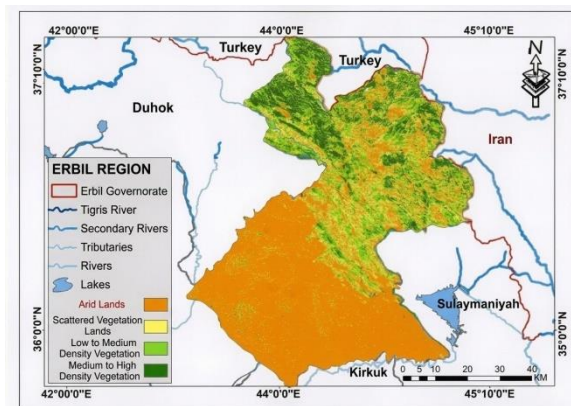
3. Sparse vegetation:

This category ranked third, covering an area of 1,857.1 km², representing 12.4% of the total area which is distributed mainly across the central parts and in proximity to surface-water resources.

4. Medium- to high-density vegetation:

This category ranked last, covering an area of 1,100.5 km², equivalent to 7.4% of the total area. It is concentrated in the northwestern sector and along the river terraces.

Accordingly, conserving and developing vegetation cover constitutes an essential condition for reducing desertification and ensuring the sustainability of agricultural production in Erbil Governorate. Natural vegetation represents the first line of defence for protecting soil and maintaining the fertility within the environmental balance system. This feature also enhances the capacity of land to withstand climatic changes and increasing human pressures and ensures the continuity of agricultural production in the long term.



Map 6
Areas of Natural Vegetation Types in the Study Area

Source: Prepared by the researcher based on the Landsat 8 imagery for 2024, using the Normalized Difference Vegetation Index (NDVI), dated (20/5/2023) and (22/5/2024).

Accordingly, conserving and developing vegetation cover is one of the most important requirements for reducing desertification and ensuring the sustainability of agricultural production in Erbil Governorate, as natural vegetation cover represents the first line of defence in protecting soil and maintaining its fertility within the environmental balance system of the region.

Second: Human Factors

Human factors are among the most prominent causes contributing to the acceleration of desertification processes and soil degradation in Erbil Governorate. Human impacts are associated with activities carried out on the land surface without taking into consideration natural characteristics or the limits of the soil's productive capacity. Among the most important of these factors are urban expansion and the construction of roads in agricultural and plateau areas, which lead to the removal of natural vegetation cover and directly expose the soil to water and wind erosion. Moreover, land levelling, foundation excavation, and road construction at the foot of slopes contribute to the removal of the natural cohesion between soil and rock

layers, thereby increasing erosion rates and reducing the soil's capacity for regeneration and production.

Overgrazing and the excessive exploitation of natural pastures are also among the most important factors that have intensified desertification manifestations in the governorate. Animal pressure on the soil surface causes soil disintegration and deterioration of its physical structure, particularly in the eastern and southern areas of Erbil. In addition, unplanned agricultural expansion and the use of inappropriate irrigation methods, such as flood irrigation in areas with low permeability, have resulted in increased salinity and hardening of surface layers, thereby reducing soil fertility and weakening its productive capacity. Furthermore, tree cutting for use as fuel or for expansion of rain-fed agriculture has exacerbated desertification rates in mountainous areas and steep slopes. Therefore, human factors constitute a major dimension in understanding the spatial relationship between soil properties and desertification manifestations because of their direct effects on agricultural production and the sustainability of natural resources in Erbil Governorate. The most important human factors affecting desertification are as follows:

1. Population Growth and Pressure on Natural Resources

Human factors constitute complementary elements to natural factors in increasing the expansion and impacts of desertification manifestations, with population growth being one of the most prominent of these factors. The rapid increase in the world's population places considerable pressure on natural resources, as people seek to meet their food and economic needs through the use of available land, resulting in the unsustainable exploitation of soil, water, and forests. Historical statistics indicate that the world's population increased from one billion people at the beginning of the previous century to more than nine billion people today, with this figure expected to increase in the future. This rapid population growth has led to the excessive use of chemical fertilizers to improve the productivity of agricultural lands, which constitutes an additional cause of soil pollution and declining fertility and, consequently, increases its susceptibility to desertification. Thus, population pressure becomes one of the fundamental causes of the gradual decline in the productive capacity of land, reflecting the close relationship between population, the environment, and the emergence of desertification.

2. Urban Expansion and the Loss of Agricultural Land

The impact of human factors is not limited to population growth but also extends to urban expansion, particularly in major cities, where urban areas increasingly occupy fertile agricultural lands surrounding them. The world has witnessed a marked

increase in the proportion of the urban population, from approximately 53% in the middle of the previous century to about 91% at the end, resulting in the expansion of cities into rural areas and the reduction of productive agricultural land. According to the United Nations Environment Programme, population expansion represents a major factor in the problem of desertification, as it contributes to the conversion of agricultural lands and natural pastures into areas vulnerable to degradation. The total built-up area of Erbil City reached 11,416 hectares in 2012 and increased to 36,187 hectares in 2025. In the center of Soran District, it increased from 9.46 km² to 77.77 km² (Ministry of Agriculture and Water Resources – Kurdistan Region, 2025, Environmental Assessment of Vegetation Cover in Erbil Governorate and Its Impact on Soil Properties, Erbil). This expansion affects not only food production but also contributes to the loss of natural vegetation cover, which constitutes the first line of defence in protecting soil from erosion and water and wind erosion.

3. Human Activities and Their Impact on Soil and Vegetation Cover

In addition to population pressure and urban expansion, unsustainable economic and agricultural activities contribute to intensifying desertification manifestations. These include overgrazing, excessive tree cutting, fires, neglect of irrigation projects and drainage systems, as well as the use of agricultural mechanization in scientifically inappropriate ways. All these practices lead to the loss of vegetation cover and soil degradation and increase the exposure of land to erosion, thereby supporting the validity of Mapot's theory, which links the degree of desertification to the level of scientific and technological advancement. The theory indicates that desertification is more evident in developing and economically underdeveloped countries as a result of their limited capacity to manage resources sustainably. Statistics indicate that the area of land threatened by desertification reaches approximately one billion hectares, equivalent to 15.4% of the world's drylands (excluding hyper-arid deserts), and that this problem affects more than 411 countries and is inhabited by approximately 15% of the world's population (Intergovernmental Panel on Climate Change, 2019), with a clear concentration in the Arab world, including Iraq, as a result of rapid population growth and urban expansion at the expense of fertile agricultural lands.

4. Human-Induced Soil Pollution and Its Impact on Agricultural Production in Erbil Governorate

The soils of Erbil Governorate face considerable challenges associated with human-induced pollution, as agricultural lands are directly affected by irrigation using water from rivers and canals that may be polluted. Moreover, the excessive use of chemical fertilizers and

insecticides and herbicides, which contain compounds such as sodium sulphate, calcium carbonate, and acids, causes substantial changes in the chemical and mechanical properties of the soil. This results in the deterioration of the soil's natural fertility and a decline in agricultural productivity. The situation becomes more severe when these substances interact with irrigation water, leading to increased levels of salinity and alkalinity in agricultural lands and transforming some areas into zones vulnerable to desertification.

The effects of salinity and alkalinity are particularly evident in the decline in the area of cultivable land in Erbil Governorate, especially in the southern areas and alluvial plains, as a result of weak and incomplete drainage networks, in addition to high groundwater levels in some lands, which intensifies salt accumulation in the soil. Even lands that have undergone reclamation continue to experience recurrent soil salinization because of poor maintenance of irrigation canals and agricultural drainage systems. This reduces the efficiency of agricultural land use and weakens its productivity. Field data indicate that this phenomenon has a substantial impact on the sustainability of agricultural production in the governorate, highlighting the importance of sustainable management of soil and irrigation water and the reduction of excessive use of chemical substances.

Second Section: Characteristics of Agricultural Production in Erbil Governorate

This section constitutes one of the fundamental components of the study, as it focuses on the characteristics of agricultural production in Erbil Governorate and the environmental factors affecting it, particularly soil and vegetation cover, which constitute the two fundamental pillars for sustaining agriculture and reducing desertification manifestations. The physical and chemical properties of soil determine the quality and efficiency of agricultural production, while natural and cultivated vegetation cover plays a major role in maintaining soil fertility and reducing erosion and degradation. Understanding this spatial relationship among the components of the terrestrial environment makes it possible to explain variations in agricultural production among the areas of the governorate during the period (1995–2025).

This section addresses three main dimensions:

First: The Importance of Soil in Agricultural Production

Soil in Erbil Governorate constitutes the fundamental basis of agricultural production, as it represents the biological reservoir of essential nutrients required for crop growth, such as nitrogen, phosphorus, and potassium. The greater the proportion of these elements and the higher the organic-matter content of the soil, the greater the effect on the quantity and quality of

agricultural production and on economic stability and food security in the region. In addition, the physical properties of soil, such as texture, depth, permeability, and water-retention capacity, directly influence crop growth, the efficiency of irrigation systems, and nutrient uptake.

In the northern and eastern plains, where deep alluvial-clayey soils predominate, favourable agricultural conditions are available to support stable irrigated agriculture. In contrast, in the southern and western areas characterized by calcareous and sandy soils, limited soil depth and high salinity reduce productivity and increase the risk of desertification, particularly during dry seasons. Therefore, understanding the spatial characteristics of soil in the governorate constitutes a fundamental basis for agricultural development planning and for identifying areas with the greatest potential for sustainable agricultural investment (Khalil, 2018, p. 145).

Second: The Role of Natural and Cultivated Vegetation Cover

Vegetation cover in Erbil Governorate represents a key environmental element linking soil, climate, and agricultural production which is not merely a source of crops but also plays an essential role in stabilizing soil and preventing erosion, maintaining its moisture and organic balance, and reducing the degradation of agricultural lands. Plant roots contribute to binding soil particles and reducing surface erosion, while decomposed plant residues enrich the soil with organic elements.

Vegetation cover varies spatially according to differences in topography and climate. The northern and eastern mountainous areas, which receive high amounts of rainfall, are characterized by dense vegetation cover consisting of forests, trees, and seasonal grasses, thereby enhancing soil fertility and stability. In contrast, the southern and western plain areas suffer from limited vegetation cover because of low precipitation and high temperatures, making them more vulnerable to erosion and desertification. Human activities, such as overgrazing and tree cutting, also contribute to the degradation of natural vegetation cover and increased erosion rates, which negatively affects agricultural production (Mustafa, 2019, p. 112).

Third: The Interaction among Soil, Vegetation Cover, and Agricultural Production

The field results demonstrate that the relationship among soil, vegetation cover, and agricultural production is interactive and integrated. Fertile soil supports plant growth, while vegetation cover, in turn, maintains soil fertility and protects the field from erosion and degradation. As human and climatic pressures, such as drought, rising temperatures, and excessive grazing, increase, soil loses organic matter and

its structure becomes disintegrated, leading to a decline in agricultural productivity and an expansion of desertified areas. Studies indicate that lands devoid of vegetation cover experience erosion rates more than fifty times higher than those of vegetated lands, demonstrating the magnitude of the protective role of vegetation in stabilizing soil and maintaining agricultural sustainability. Therefore, enhancing natural vegetation cover, improving land management, and rehabilitating degraded soils constitute essential measures for reducing desertification and achieving sustainable agricultural development in Erbil Governorate.

Third Section: Spatial Analysis Modelling of Desertification Degrees in Erbil Governorate and Their Impact on Agricultural Production

Desertification is one of the most prominent environmental problems facing Erbil Governorate because of the direct effects on the degradation of agricultural lands, the decline in agricultural production, and the loss of environmental balance. The manifestations of desertification in the region have resulted from the interaction of natural and human factors, including declining precipitation rates, rising temperatures, overgrazing, improper ploughing and ploughing against the direction of the slope using modern mechanization, repeated cultivation of the land with a single crop without leaving it fallow (exhaustive crop rotation), degradation of vegetation cover, and the unsustainable exploitation of land and water resources. To analyze the severity and spatial distribution of this phenomenon, Remote Sensing (RS) and Geographic Information Systems (GIS) techniques were employed because of their spatial and temporal accuracy in tracking environmental changes and monitoring indicators of land degradation, as follows:

First: Construction of the Spatial Model of Desertification Degrees

The analysis was based on the preparation of a Multi-Criteria Evaluation (MCE) spatial model within the ArcGIS environment using the Model Builder tool, with the aim of assessing and identifying the different risk areas within the governorate.

Relative and decimal weights were assigned to the environmental and physical factors considered most influential in desertification and were entered as inputs into this tool. These factors include:

Annual Rainfall Rate (Rainfall).

Temperature (Temperature).

Soil Type (Soil Type).

Slope (Slope).

Vegetation Density (Vegetation Density).

These data were converted into Raster layers and reclassified according to risk levels. They were then integrated using the Weighted Overlay tool based on the

relative and decimal weights presented in Table (4). Table (4) presents the relative and decimal weights of the environmental layers or factors that were entered, according to their importance, into the construction of the Multi-Criteria Evaluation (MCE) risk model for assessing desertification areas in Erbil Governorate.

This model makes this matter possible to focus on the factors with the greatest influence and those most relevant to constructing an accurate and comprehensive model. The table indicates that five principal factors influence desertification, as follows:

Annual Rainfall Rate (D1):

This represents the most important factor according to the table, as a decimal weight assigned 0.30, equivalent to 30% of the total influence. Rainfall is the primary factor determining the availability of moisture required by soil and vegetation that decline increases land vulnerability and intensifies desertification processes.

Soil Type (D2):

This factor was assigned a weight of 0.25 (25%) and directly affects the soil's capacity to retain water and nutrients. Clayey and fertile soils maintain productivity, whereas sandy or gypsum-rich soils with high permeability contribute to increasing the rate of degradation.

Vegetation Density (D3):

This factor was assigned a weight of 0.15 (15%) and reflects natural and agricultural vegetation cover, which reduces erosion and enhances soil stabilization. Low vegetation density increases the exposure of land to climatic factors and accelerates desertification.

Slope (D4):

This factor was assigned a weight of 0.10 (10%) and indicates the influence of topography on the velocity of surface runoff and water erosion. Areas with steep slopes are more vulnerable to the loss of fertile soil, whereas level lands have a greater capacity to retain soil and moisture.

Temperature (D5):

This factor was assigned a weight of 0.10 (10%) and affects soil evaporation and the rate of evapotranspiration from vegetation. High temperatures increase moisture loss and place pressure on the productive capacity of the soil.

Total:

The total weight of the factors reaches 1.00 or 100%, confirming that all the included factors constitute the comprehensive model for assessing desertification risks.

Table 4
Relative and Decimal Weights of the Input
Layers for Constructing the Desertification Risk Model
in Erbil Governorate

The influencing factor	Symbol	Relative weight	Decimal weight
Average annual rainfall	D1	30	0.30
Soil type	D2	25	0.25
Plant density	D3	15	0.15
Regression	D4	10	0.10
Temperature	D5	10	0.10
Total	—	%100	1.00

Source: Prepared by the researcher based on Table (3), Maps (3), (5), and (6), and the Landsat 8 satellite imagery for 2025.

The results of the spatial model revealed clear variation in the degrees of desertification within Erbil Governorate. The governorate was divided into five principal degrees according to the severity of desertification and the characteristics of soil and vegetation cover, as presented in Table (5) and Map (7).

Table 5
Area of Desertification Risk Levels in Erbil
Governorate

No	Degrees of Desertification risk	space	%
1	Free from Desertification	1,290km ²	9.1
2	Desertification Very slight	2,860km ²	20.1
3	Desertification Mild to moderate	6,444km ²	45.6
4	Desertification Moderate to severe	1,701km ²	12.0
5	Severe Desertification	2,280km ²	16.0
	Total	14,168km ²	100

Source: Prepared by the researcher based on Map (7).

1. Non-Desertified Lands

These lands are concentrated in the northern and northeastern parts of Erbil Governorate, within the areas of Choman, Haji Omeran, Soran, and Khelifan, and extend across the humid mountain slopes adjacent to the Iranian border. These are high-elevation areas with abundant rainfall and include valleys such as Rewanduz Valley and Balekayeti Valley, which are classified as areas of recent alluvial soils, where deep and highly moist alluvial soils predominate.

This level is represented by riverbank soils and soils characterized by very high moisture and very high vegetation density, where the soil remains unconsolidated. According to the data presented in Table (5), the area of this category in the study area reached 1,290 km², representing 9.1% of the total area of Erbil Governorate. These soils are characterized by high

fertility and an abundance of nutrients. They also retain water for long periods due to their cohesive structure and high organic-matter content, making them more environmentally and agriculturally stable. They represent the main production centers for wheat, barley, and legumes and demonstrate a high capacity to resist desertification because of the balance of their physical and chemical properties.

2. Very Slightly Desertified Lands

This category is distributed across the transitional areas between the plains and slopes, where Chromoxererts Shallow Phase soils predominate. These soils are considered close to transitional semi-arid soils (Xerochrepts). They are characterized by limited depth and relatively high exposure to water erosion during rainy seasons. Their low organic-matter content also makes them more sensitive to climatic fluctuations and drought.

Nevertheless, they still exhibit moderate resistance because part of the natural vegetation cover remains intact and traditional agricultural practices help limit their degradation. Thus, they constitute a transitional zone between stable soils and areas threatened by desertification. Table (5) indicates that the area of this category in the study area reached 2,860 km², representing 20.1% of the total area of Erbil Governorate.

3. Slight to Moderate Desertification

This category covers extensive areas of the central plains of Erbil Governorate, where Mollic Calciorthids soils predominate, which are classified as semi-arid calcareous soils (Calciorthids). These soils are characterized by moderate fertility and a balanced texture of sand and clay. However, they have begun to experience a relative increase in salinity and hardening of the surface layer as a result of excessive irrigation and the use of chemical fertilizers.

This gradual degradation leads to a decline in the productivity of field crops and deterioration of the soil's water and nutrient balance. This soil type represents a clear indicator of the transition from agricultural stability to the initial manifestations of actual desertification, particularly in intensively cultivated lands. Table (5) shows that the area of this category in the study area reached 6,444 km², demonstrating 45.6% of the total area of Erbil Governorate.

4. Moderate to Severe Desertification

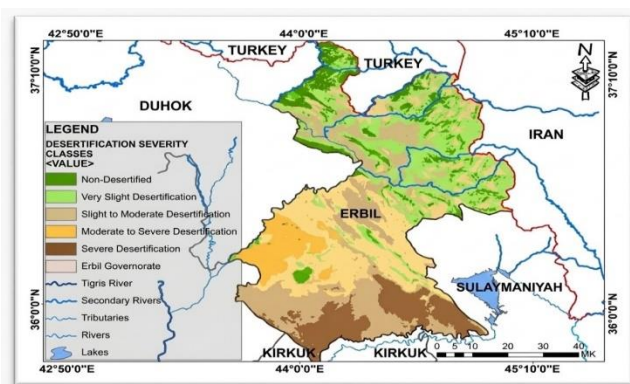
This category represents some of the most vulnerable areas in the governorate that characterized through eroded Lithic Calciorthids, in addition to exposed Bed Rock Soils, which can be classified as gypsum-rich and arid soils (Gypsiorthids-Torriorthents). These soils are characterized by shallow depth, coarse texture, a high proportion of calcium carbonate, and a very low organic-matter content.

These areas are exposed to severe wind and water erosion, together with weak permeability and high salinity. The analyses indicate that this category represents hotspots of advanced desertification manifestations, where the physical and chemical properties of the soil have deteriorated considerably, resulting in reduced agricultural production and a decline in the use of land for agriculture. Table (5) indicates that the area of this category in the study area reached 1,701 km², representing 12.0% of the total area of Erbil Governorate.

5. SEVERELY DESERTIFIED LANDS

This category represents the high mountainous areas covered by Bed Rock and Rock Debris Soils, which are classified as very dry rocky soils (Torriorthents) or highly arid saline soils (Salorthids). These lands are semi-arid and continuously exposed to weathering and slope processes, while almost completely lacking an agricultural soil cover.

They are unsuitable for permanent agriculture. However, they contribute indirectly to the expansion of desertification by supplying lower-lying basins with saline and gypsum-rich sediments transported by runoff toward low-lying agricultural lands. Table (5) indicates that the area of this category in the study area reached 2,280 km², representing 16.0% of the total area of Erbil Governorate. Therefore, these areas constitute a major environmental factor contributing to the deterioration of the fertility of agricultural soils in the central and southern parts of the governorate.



Map 7

Categories of Desertification Degrees in Erbil Governorate

Source: Prepared by the researcher based on the Landsat 8 satellite imagery for 2024 and the data presented in Table (4), using the Model Builder tool within the ArcMap 10.8 environment.

Third: Assessment of the Impact of Desertification on Agricultural Production and Soil Fertility in Erbil Governorate.

Desertification is one of the most prominent environmental challenges facing the agricultural sector in Erbil Governorate, as the effect is explicitly manifested in the deterioration of soil fertility and the long-term decline in agricultural production. Desertification processes have led to the disintegration of soil structure and the loss of organic matter and essential nutrients such as nitrogen, phosphorus, and potassium, thereby reducing the capacity of the soil to support crop growth. Wind and water erosion have also contributed to the removal of the fertile topsoil layer, particularly in the southern and western areas exposed to drought and strong seasonal winds, resulting in increased land vulnerability and reduced productivity.

At the agricultural level, natural vegetation cover and field crops have declined as a result of reduced moisture and increased salinity in some areas, particularly in calcareous and gypsiferous soils characterized by limited permeability and high salt content. Lands within the Xerochrepts and Camborthids zones have also experienced reduced productivity due to decreased soil depth and deterioration of their physical structure, which has led to a reduction in cultivated areas and the conversion of some lands into semi-arid areas.

Studies indicate that Erbil Governorate experienced a noticeable decline in agricultural production during the period between 1995 and 2025, particularly in the southern and western areas, where vegetation cover recorded declines of 43.8% in 2000, 16.3% in 2008, and 10.9% in 2012. This decline is attributed to severe drought, erosion, and increased soil salinity.

This analysis demonstrates the causal relationship between the deterioration of soil fertility and the decline in agricultural production. The loss of organic matter, increased salinity, and deterioration of soil physical structure reduce the soil's capacity to retain water and nutrients, consequently decreasing agricultural yields and making production less sustainable and more vulnerable to climatic fluctuations.

To address these challenges, the recommended and sustainable strategies for agricultural resource management adopted, including improving water and soil management through enhanced irrigation techniques, cultivating drought-resistant crops, afforestation, and land rehabilitation to enhance soil fertility and prevent erosion. Accordingly, desertification in Erbil represents a constraining factor for agricultural development and requires the adoption of integrated and sustainable solutions to ensure the continuity of agricultural production and maintain food security in the long term.

CONCLUSIONS

The study revealed an evident spatial variation in the soil properties of Erbil Governorate resulted, that sandy and sandy-loam soils are widely distributed in the southern and eastern areas and are more susceptible to erosion and soil loss caused by wind and water, making them active hotspots of desertification.

There is a positive relationship between the deterioration of the physical and chemical properties of soil and the manifestations of desertification. The findings indicate that increased salinity, reduced organic-matter content, increased bulk density, and decreased permeability contribute to declining soil fertility and reduced agricultural productivity.

Human factors have played a major role in accelerating desertification manifestations, particularly excessive ploughing of agricultural lands, overgrazing, tree cutting, and poor groundwater management. These practices have increased the severity of erosion, salinization, and surface-soil hardening.

Spatial analysis using Geographic Information Systems (GIS) revealed that areas with moderate desertification risk account for approximately 45.6% of the governorate's total area, whereas areas with severe desertification risk account for 16.0%. These areas are concentrated in the southern and western parts, which are characterized by an arid climate and sparse vegetation cover.

Natural and agricultural vegetation cover experienced a noticeable decline between 1995 and 2025 as a result of climate change, increasing periods of drought, and declining precipitation, which negatively affected the productivity of field crops, particularly wheat and barley.

Desertification in Erbil is of a complex nature, combining natural manifestations, such as erosion and soil loss, with chemical manifestations, such as salinity and alkalinity. This makes soil management a complex process requiring coordination among multiple sectors.

The variation in risk levels among the areas of the governorate indicates promising potential for restoring degraded lands in the northern and eastern areas because of their relatively more favorable soil and climatic characteristics compared with the southwestern areas.

RECOMMENDATIONS

1. Establish a unified spatial database for the soils of Erbil Governorate using Geographic Information Systems (GIS) to facilitate the periodic and up-to-date monitoring of changes in soil properties and desertification manifestations.

2. Establish a unified digital geographic database of soil properties in the governorate and update it periodically using recent satellite imagery to support environmental decision-makers.

3. Implement sustainable soil-management programs through the use of organic fertilizers, improvement of irrigation techniques, and reduction of deep ploughing, thereby contributing to the conservation of soil structure and the reduction of erosion.

4. Rehabilitate degraded lands through afforestation projects and the use of drought-resistant plant species such as Tamarix and Acacia to enhance soil stabilization and reduce sand encroachment.

5. Activate awareness and agricultural extension programs for farmers and pastoralists concerning optimal land and water-use practices and the reduction of unsustainable practices that accelerate desertification.

6. Adopt integrated water-resource management in the governorate, particularly in arid areas, through the utilization of rainfall and floodwater for water harvesting and artificial groundwater-recharge techniques.

7. Monitor climatic changes and their impacts on soil and vegetation cover using recent satellite imagery, such as Sentinel and Landsat, within a time-series framework to monitor the development of desertification indicators.

8. Incorporate desertification control into the development and agricultural plans of Erbil Governorate as a strategic objective within rural development and environmental sustainability programs.

9. Encourage joint applied research among universities and environmental and agricultural institutions to develop locally appropriate, scientifically based solutions to combat desertification and improve soil productivity.

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په یوه نډې شوې تېوان تایه تمه نډیه کانی خاک و دیارده کانی بیابانون له پاریزکای هولویر و کاریگر بیان له سر بهرهمینانی کشتوکالی بۆ ماوه (۲۰۲۵-۱۹۹۵)

پوخته

بیابانون په کیکه له مەترسیدارترین ئاستهنگه ژینگه یی هه وچه رخه کان، که تنیدا تیکچوونی تایه تمه نډیه کانی خاک (فیزیکی و کیمیاوی) ده بته هوی له دهستانانی توانای بهرهمینان و تیکچوونی هاوسهنگی ژینگه یی. ئامانجی ئهم لیکولینه ووهیه شیکردنه ووهی په یوه نډې شوې تېوان تایه تمه نډیه کانی خاک و دیارده کانی بیابانونه له پاریزکای هولویر بۆ ماوه ی تېوان سالانی ۱۹۹۵ تا ۲۰۲۵ لیکولینه ووهه که پشی به ته کیکه کانی هه سترکردن له دوروه (Remote Sensing) و سیستمی زانیاری جوگرافی (GIS) به سستوه، به تایه بقی مۆدیلی شیکردنه ووهی فره پتور (MCE) له ریکه یی ئامرازی (Model Builder) پینج هۆکاری سه رهکی هه لسه نگیندراون که بریتین له: تیکرای بارانبارین، پله یی گهرمی، جوری خاک، لیزی زهوی (Slope)، چری رووهک (NDVI) ئهم هۆکارانه به به کارهینانی ئامرازی Weighted Overlay تیکه ل کراون بۆ ده ستیشانکردنی ناوچه مەترسیداره کان. ئه نجامه کان جیاوازیه کی

روونان نیشاندوه؛ ناوچه باکووری و رۆژه لاتییه کان بهرگریان ههیه بهرامبه ر بیابانون به هوی دهوله مهندی خا که کایان به شی و مادده ی نه ندای. له بهرامبه ردا، دهشتایه باشوورییه کان به ده ست بیابانونی مامناوه ند و توند ده نالین به هوی بهرزی ریزی سویری و لاوازی پیکهاته ی خاک. ئاماره شوینییه کان ناوچه کانی بیابانونی مامناوه ند نزیکی ۳۸.۷۲٪ رووهری پاریزکاکه پیکده هین، له کاتیکدا ناوچه زور بیابانونه کان که یشتونه ته ۱۵.۶۹٪، که ئهم ناوچانه دابه زینیکی توندیان له بهرهمینانی کشتوکالیدا به خوه یینوه. هۆکاره مروییه کان (خرابی بهرپوه بردن، زیاده رویی له ئاودیری، فراوانبونی شارنیشینی) له گه ل هۆکاره که شوه واییه کان (وشکه سالی و بهرزیوونه ووهی پله یی گهرمی) په کایان گرتوه بۆ خراپترکردنی دیارده که. ئه مته ش مەترسی لقسره کشته سته ندنی ئابووری له ناوخته که دروست ده کات، لیکولینه ووهه که جهخت له کارایی ته کیکه کانی GIS ده کاتمه له چاودیری کردنی گۆرانکارییه کانی بیابانون به وردیه کی بهرزی، ئه مه ش وا ده خوازی ت وهک ئامرازیکی به رهقی پشی پی به ستریت بۆ پالپشتیکردنی پلانه کانی بهرپوه بردنی ژینگه یی بهرده وام و پاراستنی ئاسایشی خوراک له پاریزگاکه دا.

وشه سه ره کیه کان: بیابانون، تایه تمه نډیه کانی خاک، تیکچوونی زهوی، بهرهمینانی کشتوکالی، هه سترکردن له دوروه.

العلاقة المكانية بين خصائص التربة ومظاهر التصحر في محافظة أربيل وأثرها على الإنتاج الزراعي للمدة (١٩٥٥-٢٠٢٥)

الملخص

يُمثل التصحر أحد أخطر التحديات البيئية المعاصرة، حيث يؤدي تدهور خصائص التربة (الفيزيائية والكيميائية) إلى فقدان قدرتها الإنتاجية واختلال التوازن البيئي. تهدف هذه الدراسة إلى تحليل العلاقة المكانية بين خصائص التربة ومظاهر التصحر في محافظة أربيل للمدة بين 1995 و 2025، اعتمد البحث على تقنيات الاستشعار عن بُعد ونظم المعلومات الجغرافية (ArcGIS)، وتحديدًا نموذج التحليل متعدد المعايير (MCE) عبر أداة (Model Builder)، تم تقييم خمسة عوامل رئيسية: (معدل الأمطار، درجة الحرارة، نوع التربة، الانحدار، والكثافة النباتية)، ودمجها باستخدام أداة (Weighted Overlay) لتحديد مناطق الخطورة. أظهرت النتائج تباينًا واضحًا؛ فالأراضي الشالية والشرقية تمتاز بمقاومة التصحر لغنى تربتها بالرطوبة والمواد العضوية. في المقابل، تعاني المنطقة المتوجة الواقعة في الجنوب من تصحر متوسط إلى شديد بسبب ارتفاع الملوحة وضعف بنية التربة. تشغل مناطق التصحر المتوسط نحو (45.60%) من مساحة المحافظة، بينما بلغت المناطق شديدة التصحر (16.0%)، وهي مناطق شهدت تراجعاً حاداً في الإنتاج الزراعي. تضافرت العوامل البشرية (سوء الإدارة، الإفراط في الري، التوسع العمراني) مع العوامل المناخية (الجفاف وارتفاع الحرارة) لتفاقم الظاهرة. ، مما يهدد التنمية الاقتصادية بالمنطقة. تؤكد الدراسة على كفاءة تقنيات (GIS)، في رصد ديناميكية التصحر بدقة عالية، مما يستوجب اعتمادها كأداة أساسية لدعم خطط الإدارة البيئية المستدامة وحماية الأمن الغذائي في المحافظة.

الكلمات المفتاحية: التصحر، خصائص التربة، تدهور الأراضي، الإنتاج الزراعي، الاستشعار عن بُعد.