Geospatial Analysis of Urban Expansion and Vegetation Dynamics in Kirkuk Governorate Utilizing Remote Sensing Technologies

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Abstract

Rapid urban expansion is a key driver of land use and land cover (LULC) transitions, causing spatial and environmental transformations that directly challenge natural resource sustainability. This study uses remote sensing (RS) datasets and Geographic Information Systems (GIS) to analyze the spatial dynamics of urban expansion and its subsequent consequences on vegetation dynamics in Kirkuk Governorate. By analyzing multi-temporal satellite images, the study maps historical land cover changes and estimates the trajectory and scale of urban sprawl throughout the specified era. Furthermore, the Normalized Difference Vegetation Index (NDVI) was used to track changes in biomass density and identify specific areas affected by green space deterioration. The spatial empirical results show a significant increase in built-up settings, which is closely correlated with a significant loss of surrounding vegetation, especially in areas outside of main metropolitan centers. The results reveal a strong negative spatial link between the distribution of vegetation and horizontal urban growth; the governorate's ecological stresses have increased due to the systematic encroachment of green spaces by accelerated construction operations. In the end, these observations emphasize how important it is to incorporate geospatial technologies into frameworks for environmental monitoring. Monitoring urban dynamics, directing sustainable municipal planning, reducing unchecked sprawl, and preserving Kirkuk Governorate's ecological integrity all depend on this kind of integration.

Keywords: Kirkuk Governorate; Urban Growth; Vegetation Cover; Remote Sensing; Geographic Information Systems; NDVI; Land Use Change.

Introduction

In recent decades, the world has witnessed a remarkable increase in urban growth rates driven by population growth, economic development, and the expansion of human activities. This surge has led to fundamental alterations in land use and land cover (LULC) patterns. Urban sprawl stands out as one of the most prominent manifestations of these shifts, causing the conversion of vast tracts of agricultural land and natural habitats into built-up areas, which negatively impacts ecological balance and the sustainability of natural resources.

Vegetation cover is one of the most critical environmental components affected by urbanization. Urban expansion continuously reduces green spaces, fragments of natural habitats, and degrades the ecosystem services provided by plants, such as improving air quality, regulating local climate, and mitigating soil degradation. Consequently, monitoring the spatial dynamics of urban growth and its impacts on vegetation cover has become a pivotal topic in geographical and environmental studies. It provides essential data that supports sustainable urban planning and natural resource management.

The significant advancements in Remote Sensing (RS) and Geographic Information Systems (GIS) technologies have yielded highly effective tools for monitoring and analyzing spatial and temporal changes in land use and land cover with high accuracy and lower costs compared to traditional methods. Multi-temporal satellite imagery serves as a primary data source for tracking urban sprawl patterns and assessing associated environmental changes. Meanwhile, the Normalized Difference Vegetation Index (NDVI) is widely utilized to estimate vegetation density and monitor its fluctuations over time.

Kirkuk Governorate is one of the Iraqi provinces that has experienced accelerating urban expansion in recent years due to population growth and urban development, which has directly influenced local land use patterns and vegetation cover. Against this backdrop, studying the relationship between urban growth and vegetation dynamics becomes highly significant to uncover the magnitude of these changes, their spatial trajectories, and to identify the areas most affected by them.

Therefore, this research aims to analyze the spatial changes of urban growth in Kirkuk Governorate using remote sensing and GIS techniques. It also evaluates its impact on vegetation cover through satellite imagery analysis and NDVI computation. Ultimately, this study seeks to provide a spatial database that assists decision-makers, enhances the foundations of sustainable urban planning, and preserves environmental resources within the study area.

Research Problem

In recent years, Kirkuk Governorate has experienced rapid urban expansion driven by population growth, economic development, and increased construction activities. This expansion has led to noticeable shifts in land use and land cover (LULC) patterns. Consequent to this sprawl, a decline in vegetation cover and escalating environmental pressures have emerged. However, the exact magnitude of these changes, their spatial distribution, and the precise impact of urban growth on vegetation cover still require accurate quantitative and spatial analysis using modern technologies. Accordingly, the research problem can be articulated through the following primary question:

-What is the nature of the spatial changes in urban growth within Kirkuk Governorate, and to what extent has it impacted vegetation cover during the study period using remote sensing and geographic information systems (GIS) techniques?

Research Hypothesis

The research is based on the following hypothesis: There is a negative spatial correlation between urban growth and vegetation cover in Kirkuk Governorate, whereby increasing urban expansion leads to a decrease in the area of vegetation cover and a decline in its density within the zones affected by urban growth.

Research Objective

The research aims to:

1. **Analyze** the spatial distribution of urban growth in Kirkuk Governorate during the study period.
2. **Detect** the trends and rates of urban expansion using satellite imagery.
3. **Measure** the changes in vegetation cover using the Normalized Difference Vegetation Index (NDVI).
4. **Determine** the spatial relationship between urban expansion and vegetation to cover dynamics.
5. **Produce** thematic maps illustrating urban growth patterns and areas of vegetation decline.
6. **Provide** spatial data to support sustainable urban planning and environmental resource conservation.

Significance of the Research

The significance of this research stems from its focus on one of the most critical environmental challenges associated with urban expansion and its direct impacts on vegetation cover in Kirkuk Governorate. Furthermore, its importance lies in the integration of remote sensing (RS) and Geographic Information Systems (GIS) technologies to monitor and analyze spatial dynamics with high precision. This contributes to establishing a spatial database that assists decision-makers in formulating sustainable development plans and mitigating the environmental impacts resulting from unorganized urban sprawls. Additionally, this study enriches geographical literature concerning land use and land cover (LULC) dynamics.

Research Methodology

The study adopts a spatial analytical approach utilizing remote sensing (RS) and Geographic Information Systems (GIS) technologies to investigate spatial changes in urban growth and vegetation cover. Multi-temporal satellite imagery was employed to monitor urban expansion and generate land use and land cover (LULC) maps, alongside applying the Normalized Difference Vegetation Index (NDVI) to assess vegetation dynamics. Furthermore, digital image processing (DIP) was performed on satellite datasets, followed by a spatio-temporal analysis of the results to uncover the correlation between urban growth and vegetation cover alterations within the study area.

Research Tools and Data:

The study relies on a suite of datasets, software applications, and analytical tools, detailed as follows:

1. Multi-temporal satellite imagery from Landsat missions.

2. Administrative boundary data for Kirkuk Governorate.
3. ArcGIS Pro (or ArcMap) software for conducting spatial analyses and cartographic production.
4. ERDAS IMAGINE software (or Google Earth Engine) for digital image processing of satellite imagery.
5. The Normalized Difference Vegetation Index (NDVI) evaluates vegetation cover status.
6. Change Detection techniques to monitor spatio-temporal dynamics and transitions.

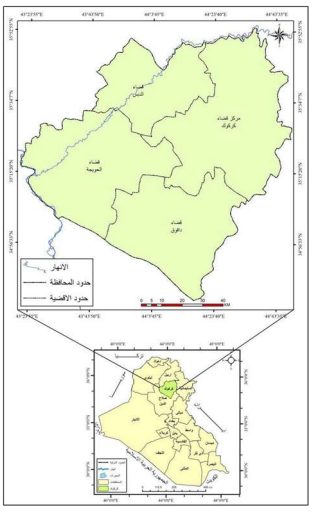
Study Area:

Kirkuk Governorate is located in the northeastern part of Iraq, situated within the transitional zone between the Mesopotamian alluvial plain and the northern plateau. It occupies a distinct geographical location that renders it highly significant from both economic and urban perspectives. It is bordered by Erbil Governorate to the north, Sulaymaniyah Governorate to the east, Salah al-Din Governorate to the west and southwest, and Diyala Governorate to the southeast.

The total area of the governorate is approximately 9,679 km^2, comprising several primary administrative units: the center of Kirkuk District, and the districts of Al-Hawija, Al-Dibs, and Daquq. The region is also intersected by several watercourses that have historically driven agricultural activities and human settlement. Astronomically, the governorate lies between latitudes 34°56′33″ and 35°52′55″ N, and longitudes 43°23′55″ and 44°43′35″ E.

The geographical location of Kirkuk Governorate serves as a major driver for its urban growth and expansion. In recent decades, the governorate has experienced a substantial increase in built-up areas resulting from population growth and economic development, which has directly affected local land use and vegetation cover patterns. Consequently, it was selected as the study area to analyze the spatial dynamics of urban growth and determine its impacts on vegetation cover utilizing remote sensing and Geographic Information Systems (GIS) technologies.

Map (1): Location of the Study Area



Source: Prepared by the researcher based on the administrative boundary data of the Republic of Iraq and Kirkuk Governorate, obtained from the Iraqi General Directorate of Survey, and processed using ArcMap 10.8 software.

Spatial Distribution of Urban Areas in Kirkuk Governorate (2000)

Spatial distribution refers to the manner in which a geographical phenomenon is dispersed across the Earth's surface according to specific patterns and spatial relationships. Urbanization, on the other hand, denotes the process of population growth alongside the expansion of economic and service activities within cities, accompanied by an increase in built-up areas at the expense of other land uses. Urbanization represents one of the most prominent manifestations of spatial change that directly affects land use and land cover (LULC) patterns, leading to the reshaping of the geographical landscape and the emergence of new urban centers or the expansion of existing ones.

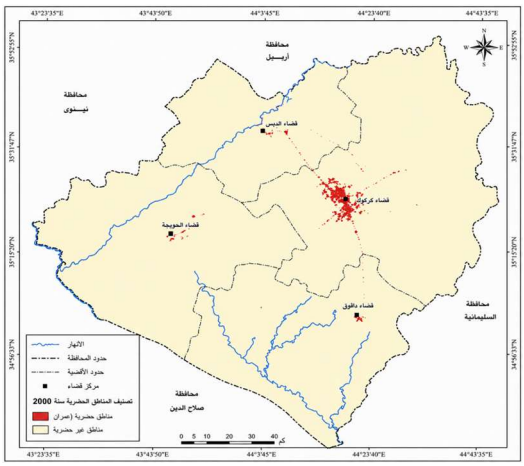
The spatial distribution map of urban areas in Kirkuk Governorate for the year 2000 reveals that urban development was primarily concentrated in the center of Kirkuk District, which constitutes the largest urban core in the governorate. Meanwhile, smaller and less dispersed urban agglomerations appeared in the district centers of Al-Hawija, Al-Dibs, and Daquq. This concentration reflects the administrative and economic role played by Kirkuk City as the governorate's capital, in addition to its hosting of commercial, service, and industrial activities, as well as major transportation networks that served to attract population and intensify construction activities.

The map further indicates that the urban distribution adopted a clustered pattern around main urban centers, with limited linear extensions along major roadways. This highlights the influence of transportation networks and infrastructure in guiding urban expansion. Conversely, the western and southern regions of the governorate exhibited low urban density compared to the central and eastern parts, a variance attributed to the dominance of agricultural land use, vast open spaces, and the scarcity of urban activities during that period.

These findings demonstrate that the total area of urban zones was relatively limited in 2000 compared to the overall area of the governorate, reflecting an earlier urban phase prior to the accelerating waves of rapid urbanization experienced in subsequent years. This specific urban distribution increased environmental pressures on lands surrounding urban centers—particularly agricultural fields and vegetated areas adjacent to human settlements—thereby laying the groundwork for subsequent spatial shifts in land use and land cover patterns.

Consequently, the map of the year 2000 serves as the definitive baseline from which subsequent urban growth trends can be measured, the magnitude of structural changes in the urban landscape quantified, and the impacts of this expansion on local vegetation cover and the environment in Kirkuk Governorate evaluated.

Map (2): Urban Areas Classification (2000)



Source: Prepared by the researcher based on Landsat 7 ETM+ satellite imagery for the year 2000 and the administrative boundary data of Kirkuk Governorate, processed using ArcMap 10.8 software.

Spatial Distribution of Urban Areas in Kirkuk Governorate (2025)

The spatial distribution map of urban areas in Kirkuk Governorate for the year 2025 provides a clear depiction of the magnitude of urban expansion experienced by the governorate in recent years. This urban distribution is characterized by a remarkable increase in built-up areas and a wider scope of dispersion compared to the baseline year. In this context, the spatial distribution of urban areas signifies the pattern of expansion and settlement of urban agglomerations across the Earth's surface, alongside the spatial relationships that bind them to the physical and anthropogenic factors influencing their growth.

The map clearly illustrates that the center of Kirkuk District captured the largest urban agglomeration in the governorate, where the primary urban mass concentrated and extended outward toward the surrounding peripheries in almost all directions. This expansion reflects the status of Kirkuk City as the administrative, economic, and service hub of the governorate. This sprawl is attributed to population growth, expanding commercial and industrial activities, and the development of transportation networks and essential services, which collectively drove up the demand for residential land and forced the urban footprint to expand beyond its previous boundaries.

Furthermore, the map reveals distinct urban expansion within the districts of Al-Dibs, Al-Hawija, and Daquq. Built-up areas around these district centers increased, accompanied by the emergence of linear urban extensions along the major highway corridors connecting them to the governorate's capital. This underscores the pivotal role that transportation and transit networks play in steering urban growth and determining its spatial trajectories, as urbanized areas tend to expand adjacent to major mobility axes due to accessibility and service availability.

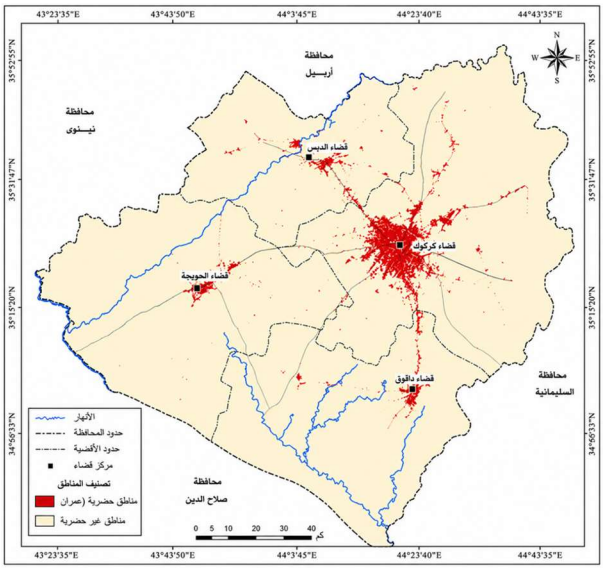
The analysis also uncovers a clustered spatial pattern of urban development within the governorate's capital, contrasted with lower-density patterns in the outskirts. This variation indicates the persistence of urban concentration in Kirkuk City relative to the remaining administrative units. Additionally, the proliferation of several small-to-medium urban settlements is observed outside the primary urban centers,

reflecting the encroachment of urban influence into neighboring rural zones and the conversion of portions of open spaces into urban land uses.

This urban expansion has entailed a series of spatial and environmental repercussions. These are manifested in the increased consumption of land surrounding urban cores and the conversion of agricultural tracts and vegetated areas into built-up surfaces, thereby resulting in a decline in green spaces and intensifying pressures on natural resources. Moreover, this urban sprawl has altered land use patterns and reshaped the geographical landscape of the governorate, particularly within zones adjacent to the center of Kirkuk District.

Consequently, the map confirms that Kirkuk Governorate underwent accelerating urban growth during the study period, characterized by an increase in both the area and dispersion of built-up zones. This makes it an essential foundation for understanding subsequent spatial dynamics and analyzing the impact of urban sprawl on vegetation cover and land use within the study area.

Map (3): Urban Areas (2025)



Source: Prepared by the researcher based on Landsat 8 OLI satellite imagery for the year 2025 and the administrative boundary data of Kirkuk Governorate, processed using ArcMap 10.8 software.

Spatial Dynamics of Urban Growth in Kirkuk Governorate (2000–2025)

The spatial dynamics of urban growth represent the temporal transformations in the magnitude and distribution of built-up areas, driven by urban expansion, population growth, economic development, and infrastructure advancement. Spatial change maps serve as a critical tool for monitoring urban expansion trends and identifying zones undergoing land use transitions, as they clearly delineate existing urban areas, newly expanded zones, and their dispersion patterns within the study area.

The map illustrates a pronounced urban expansion across Kirkuk Governorate during the 2000–2025 period, with the most substantial growth concentrated in the center of Kirkuk District, which serves as the governorate's primary urban core. Notably, this expansion did not occur randomly; rather, it adopted a

radial pattern extending from the city center toward the peripheries and along major transportation corridors. This emphasizes the pivotal role of road networks and infrastructure in directing the trajectory of urban growth.

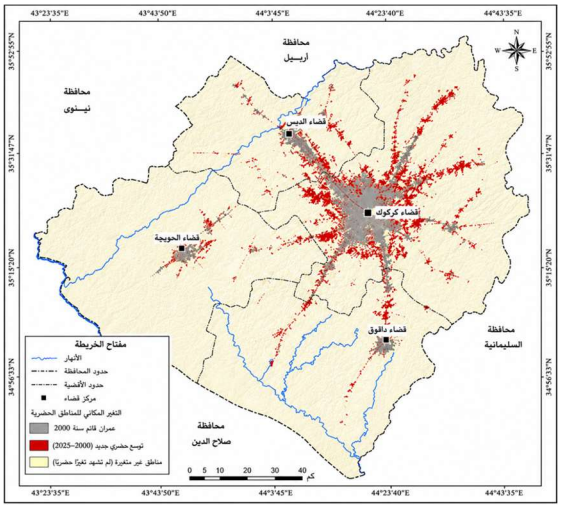
Furthermore, the map reveals the emergence of new built-up areas surrounding the district centers of Al-Dibs, Al-Hawija, and Daquq, though the scale of this expansion was minor compared to the center of Kirkuk District. This disparity is attributed to differences in population sizes and the centralization of economic and service activities among the governorate's districts. Kirkuk City continues to attract the highest proportion of administrative, commercial, and industrial operations, thereby elevating the demand for residential and service lands.

Spatially, urban expansion was predominantly concentrated in the central and northeastern parts of the governorate, while growth rates remained relatively lower in the western and southern regions. This variance is linked to geographic location characteristics, population distribution, transport networks, and service availability, alongside differing land use patterns across the governorate.

The analysis further discloses the conversion of extensive land tracts surrounding urban centers into newly built-up environments, reflecting accelerating urbanization processes throughout the study period. Consequently, this has intensified pressures on natural resources and led to a decline in agricultural practices and vegetated areas adjacent to cities, particularly within zones experiencing the highest rates of urban development.

These findings confirm an accelerating urban growth within Kirkuk Governorate during the studied timeframe, as built-up areas expanded beyond their original boundaries of the year 2000, thereby reshaping the governorate's spatial landscape. This expansion constitutes a primary driver of subsequent vegetation cover alterations, underscoring the critical importance of investigating the relationship between urban growth and environmental change to meet the requirements of sustainable urban development and resource conservation within the study area.

Map (4): Spatial Dynamics of Urban Growth in Kirkuk Governorate (2000–2025)



Source: Prepared by the researcher based on Landsat satellite imagery for the years 2000 and 2025, and processed using ArcMap 10.8 software.

Spatial Distribution of Vegetation Cover (NDVI) in Kirkuk Governorate (2000)

The Normalized Difference Vegetation Index ($NDVI$) is one of the most widely utilized indices in remote sensing studies to assess the status and density of vegetation cover, as it computes the difference between spectral reflectance in the red and near-infrared (NIR) bands. High $NDVI$ values indicate dense, highly viable vegetation, whereas low or negative values correspond to bare lands or areas with sparse vegetation cover.

The spatial distribution map of vegetation cover in Kirkuk Governorate for the year 2000 reveals a distinct variation in vegetation distribution across different parts of the governorate. High index values and dense vegetation cover were concentrated in the northern, northeastern, and eastern portions of the governorate, particularly within zones adjacent to the administrative boundaries of Erbil and Sulaymaniyah Governorates. This concentration is attributed to favorable environmental conditions regarding precipitation rates, soil characteristics, and terrain, in addition to the prevalence of agricultural activities in those regions.

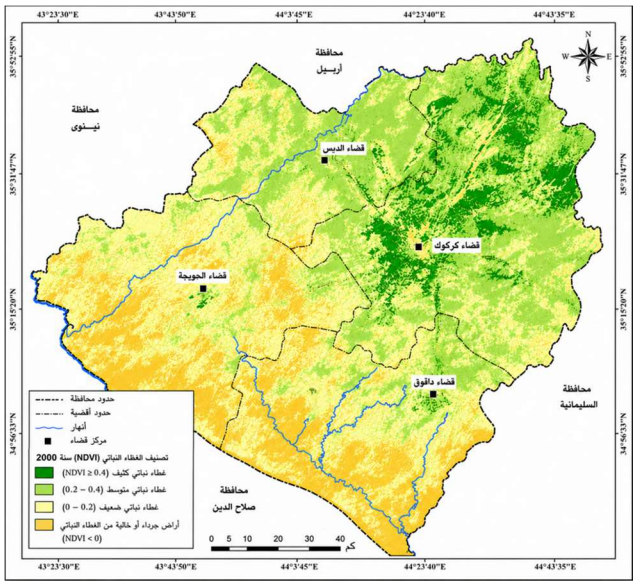
Furthermore, the map indicates extensive tracts of moderately dense vegetation cover throughout the central parts of the governorate, especially surrounding Kirkuk and Al-Dibs districts. In these areas, water resources and irrigation networks supported agricultural practices and sustained the green cover during the study period. These areas function as a transitional zone between high-density and low-density vegetation sectors.

Conversely, bare lands and sparse vegetation areas were concentrated in the western and southwestern parts of the governorate, notably within the Al-Hawija District and certain southern sectors. This decline is driven by lower precipitation rates, higher evaporation rates, and the expansion of semi-arid terrains, which collectively suppressed vegetation density compared to the northern and eastern portions.

Spatially, a clear correlation is observed between the distribution of vegetation cover and the network of rivers and watercourses, with vegetation density increasing near water resources due to the availability of optimal conditions for agricultural stability and green cover maintenance. Additionally, the map shows that urban areas occupied relatively limited expanses in 2000, which allowed extensive vegetated tracts to persist without facing significant urban pressures.

These findings demonstrate that Kirkuk Governorate possessed a relatively healthy vegetation cover during the baseline year, with green spaces visibly concentrated in the northern and eastern regions. Consequently, this map serves as a fundamental baseline reference to evaluate subsequent alterations in vegetation cover and measure the extent of its vulnerability to the urban expansion experienced by the governorate in later years, particularly when compared against the 2025 map and the spatial change map of vegetation cover.

Map (5): Spatial Distribution of Vegetation Cover (NDVI) in Kirkuk Governorate (2000)



Source: Prepared by the researcher based on Landsat 7 ETM+ satellite imagery for the year 2000 and the administrative boundary data of Kirkuk Governorate, with the Normalized Difference Vegetation Index (NDVI) processed using ArcMap 10.8 software.

Spatial Distribution of Vegetation Cover (NDVI) in Kirkuk Governorate (2026)

Analysis of the spatial distribution map of vegetation cover (NDVI) in Kirkuk Governorate for the year 2026 reveals a distinct variation in vegetation density across different parts of the governorate. The $NDVI$ remains one of the most vital indices utilized in remote sensing to estimate the density and viability of green cover, where high values indicate dense vegetation, while low values signify sparse vegetation or the dominance of bare lands.

The map demonstrates that the dense vegetation category (0.40 \le \text{NDVI} \le 0.70) was concentrated in the northern, northeastern, and eastern portions of the governorate, particularly within zones adjacent to Erbil and Sulaymaniyah Governorates, appearing as extensive areas shaded in dark green. This pattern is strongly linked to favorable environmental conditions, the availability of water resources, and the centralization of agricultural activities in those regions.

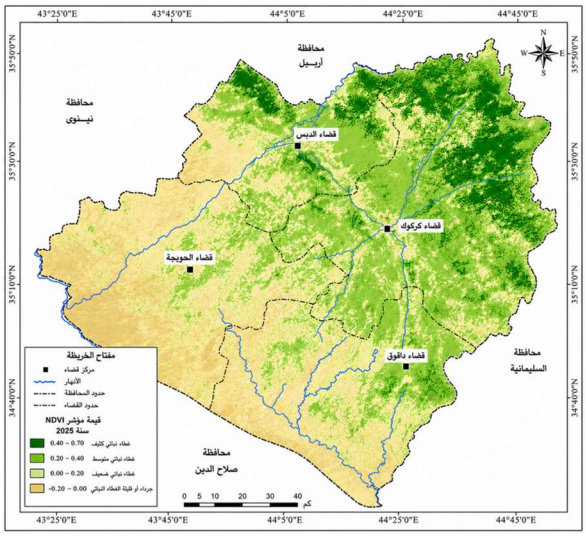
Meanwhile, the moderate vegetation category ($0.20 \le \text {NDVI} < 0.40$) was widely dispersed throughout the central parts of the governorate, forming a transitional belt between the high-density vegetation zones and the less dense sectors. The distribution of this category reflects the presence of agricultural lands and pastures characterized by varying degrees of vegetative density.

Conversely, the sparse vegetation category ($0.00 \le \text {NDVI} < 0.20$) was concentrated in the western, southwestern, and southern parts of the governorate, especially within vast expanses of Al-Hawija District and the southern sectors of Daquq District. These areas are significantly impacted by limited precipitation and elevated rates of relative aridity.

Furthermore, the map highlights the proliferation of bare lands or extremely low vegetative cover ($-0.20 \le \text{NDVI} < 0.00$) along the southern and western peripheries. This distribution reflects suppressed vegetative activity and the dominance of environmental conditions that are less conducive to plant growth compared to the northern and eastern parts.

Spatially, these results indicate a clear correlation between elevated $NDVI$ values and the network of rivers and watercourses, as vegetation density increases adjacent to water sources. This underscores the pivotal role of water resources in supporting agricultural practices and sustaining vegetation cover within Kirkuk Governorate.

Map (6): Spatial Distribution of Vegetation Cover (NDVI) in Kirkuk Governorate (2025)



Source: Prepared by the researcher based on Landsat 8 OLI/TIRS satellite imagery for the year 2025 and the administrative boundary data of Kirkuk Governorate, processed using ArcMap 10.8 software.

Spatial Dynamics of Vegetation Cover Change in Kirkuk Governorate (2000–2025)

The spatial dynamics of vegetation cover change represent the temporal transformations in the distribution and density of green cover, driven by the interactions of various physical and anthropogenic factors. Investigating these dynamics serves as a critical indicator for assessing natural resource efficiency and evaluating its vulnerability to environmental shifts and land use transitions, particularly in regions experiencing rapid urbanization. The spatial change map of vegetation cover in Kirkuk Governorate during the 2000–2025 period delineates the trajectories of increase, degradation, and stability within the study area.

The map indicates that the "vegetation stability" category occupied the largest area of the governorate, covering $4,729 \text{km}^2$ and accounting for 48.86% of the total baseline area. This dominance signifies the persistence of vegetative characteristics across extensive portions of the region and their resilience against fundamental alterations during the study period. These areas are widely distributed

throughout the governorate, particularly within stable agricultural zones and terrains that maintain their traditional land-use patterns.

Furthermore, the map reveals a "vegetation increase" across an area of $2,150 \text{km}^2$, representing 22.21% of the governorate's total surface. This growth is predominantly concentrated in the northern, northeastern, and eastern sectors of the governorate, driven by enhanced agricultural practices, the development of irrigation projects, and targeted cropland cultivation, alongside favorable physical conditions in those zones relative to the rest of the governorate.

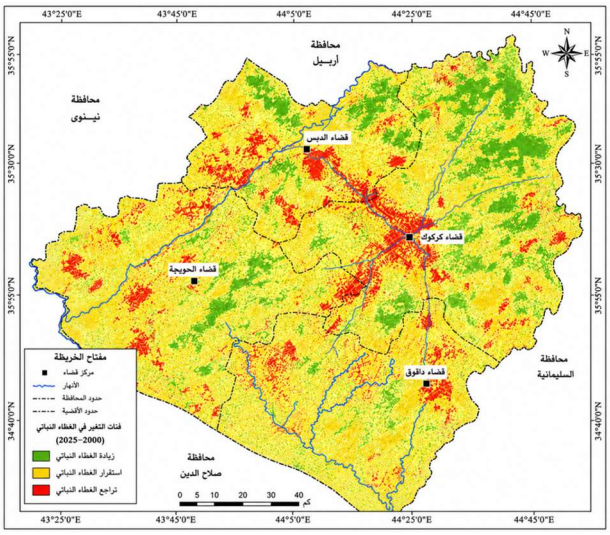
Conversely, areas of "vegetation degradation" recorded an expanse of $2,800 \text{ km}^2$, constituting 28.93% of the total governorate area. This loss is visibly distributed around the center of Kirkuk District and other primary district centers, as well as along linear corridors adjacent to major transportation axes and highways. This spatial configuration directly reflects the immediate footprint of urban expansion and the conversion of agricultural tracts and green zones into built-up, residential, and service infrastructures throughout the study period.

The analysis demonstrates that the highest rates of vegetation degradation were clustered in the peripheries surrounding Kirkuk City, where zones of decline intersected precisely with sectors that recorded high urban growth on the spatial dynamics map of urban expansion. This correspondence emphasizes an inverse spatial correlation between urban sprawl and vegetation cover; as built-up areas expand, adjacent green spaces contract.

Moreover, the spatial distribution of these change categories highlights that terrains distant from primary urban centers maintained higher degrees of stability or exhibited localized vegetation gains, whereas degradation zones were concentrated strictly within the direct sphere of anthropogenic influence. This disparity underscores the decisive role that land use transitions play in reshaping the governorate's environmental landscape.

Consequently, these findings confirm that Kirkuk Governorate underwent distinct spatial transformations in its vegetation cover during the 2000–2025 timeframe, where urban expansion coincided with a contraction of green spaces, while other regions preserved their stability or registered relative improvements in canopy density. This map provides critical spatial evidence of the impact of urban growth on the local environment, serving as the scientific foundation for analyzing the direct spatial relationship between urban expansion and vegetation cover dynamics within the study area.

Map (7): Spatial Dynamics of Vegetation Cover Change in Kirkuk Governorate (2000–2025)



Source: Prepared by the researcher based on Landsat satellite imagery for the years 2000 and 2025, with NDVI analysis conducted using ArcMap 10.8 software.

Spatial Correlation Between Urban Growth and Vegetation Cover Change in Kirkuk Governorate (2000–2025)

The spatial correlation between urban growth and vegetation cover change constitutes a critical indicator for assessing the environmental impacts induced by urban sprawl, as it helps identify areas undergoing land use conversions where built-up environments expand at the expense of agricultural lands or vegetated zones. This relationship was derived through a spatial overlay analysis between the urban expansion map and the vegetation cover change map, aiming to detect the nature of mutual feedback between both phenomena within Kirkuk Governorate.

The analysis reveals that the category of "urban expansion coupled with vegetation degradation" occupied an area of $2,156 \text{km}^2$, accounting for 22.27% of the total governorate area. This represents the highest category of direct urban growth impact on green cover. These areas were visibly clustered around the center of Kirkuk District and along the primary corridors leading to Al-Dibs, Daquq, and Al-Hawija districts, demonstrating that urban sprawl was the primary driver behind the loss of extensive green spaces during the study period.

Furthermore, the map highlights the category of "urban expansion with stable vegetation," covering an area of 642km^2 (6.63%). This represents regions that experienced localized urban growth without triggering substantial alterations in the surrounding vegetation, reflecting variations in urban development intensity across different parts of the governorate.

Conversely, the category of "urban expansion simultaneous with vegetation increase" recorded at the smallest spatial extent, covering 202km^2 (2.09%). This category is concentrated in specific areas that underwent limited urban development alongside the expansion of managed green spaces or

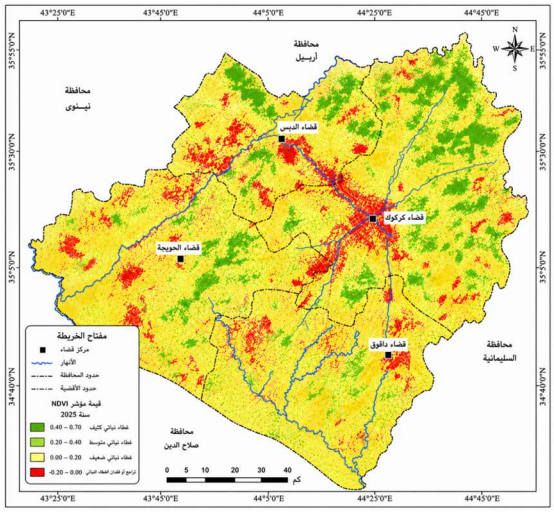
irrigated agricultural practices, indicating that this pattern was highly localized compared to other dynamics.

The results further demonstrate that the category of "vegetation degradation without direct urban expansion" encompassed 644km^2 (6.65%), which is attributed to other physical and anthropogenic drivers, such as climate variability, land degradation, or shifts in agricultural practices. Meanwhile, the category of "vegetation increase without urban expansion" spanned $1,948 \text{km}^2$ (20.11%), reflecting the role of agricultural initiatives and irrigation projects in improving canopy density across certain sectors of the governorate.

Notably, the category of "vegetation stability without direct urban impact" registered the largest spatial extent among all analyzed categories, covering $4,087 \text{km}^2$ and representing 42.25% of the total governorate area. This indicates that vast portions of the study area did not undergo fundamental shifts during the studied timeframe.

These findings confirm a distinct inverse spatial correlation between urban growth and vegetation cover in Kirkuk Governorate, as urban sprawl zones intersected precisely with sectors experiencing the highest rates of vegetation loss, particularly around the governorate center and primary district cores. Consequently, these analytical outcomes validate the research hypothesis, which asserts that escalating urban expansion drives vegetation degradation and triggers the conversion of agricultural lands and green fields into various built-up uses.

Map (8): Spatial Correlation Between Urban Growth and Vegetation Cover Change in Kirkuk Governorate (2000–2025)



Source: Prepared by the researcher based on the results of the spatial overlay analysis between the urban expansion map (2000–2025) and the vegetation cover change map (NDVI) for the same period, utilizing Landsat 7 ETM+ satellite imagery for the year 2000 and Landsat 8 OLI/TIRS for the year 2025, processed using ArcMap 10.8 software.

Table (1): Summary of Spatial Analysis Results for Urban Growth and Vegetation Cover in Kirkuk Governorate

Axis	Category	Area (km2)	Percentage (%)
Vegetation Cover Change	Vegetation Increase	2150	22.21
	Vegetation Stability	4729	48.86
	Vegetation Degradation	2800	28.93
Urban Growth & Vegetation Correlation	Urban Expansion coupled with Vegetation Degradation	2156	22.27
	Urban Expansion with Stable Vegetation	642	6.63
	Urban Expansion coupled with Vegetation Increase	202	2.09
	Vegetation Degradation without Urban Growth	644	6.65
	Vegetation Increase without Urban Growth	1948	20.11
	Vegetation Stability without Urban Growth	4087	42.25
Vegetation Cover Distribution (2025)	Dense Vegetation	2980	30.79
	Moderate Vegetation	2912	30.07
	Sparse Vegetation	2507	25.9
	Bare Lands or Extremely Low Vegetation	1280	13.24
	Total	9679	100

Source: Prepared by the researcher based on the spatial analysis results of Landsat satellite imagery for the years 2000 and 2025.

Spatial analysis incorporating remote sensing (RS) techniques and geographic information systems (GIS) demonstrates that Kirkuk Governorate experienced distinct spatiotemporal transitions in land use and land cover (LULC) patterns during the 2000–2025 period. These transformations were primarily characterized by accelerated urban expansion and shifting vegetative density configurations. Spatiotemporal maps of built-up distribution indicate that urban fabric in the year 2000 was strictly confined to the center of Kirkuk District, with localized urban clusters dispersed across Al-Dibs, Al-Hawija, and Daquq districts. However, this nucleated pattern expanded progressively up to 2025, culminating in extensive built-up corridors aligned along major transportation axes and highways interconnecting the primary district centers.

The urban growth dynamics map reveals that Kirkuk City monopolized the largest share of built-up expansion relative to the rest of the governorate. The city's urban growth exhibited a radial pattern, sprawling outward from the historical urban core toward the rural peripheries, whereas more subdued urban growth was observed around secondary district centers. This spatial behavior reflects the direct footprint of demographic growth, shifting economic and service activities, and transport infrastructure development, all of which amplified the demand for urban land.

Regarding environmental dynamics, the Normalized Difference Vegetation Index (NDVI) maps for the years 2000 and 2025 delineate a profound spatial disparity across the governorate sectors. Dense and moderate vegetation classes were heavily clustered within the northern, northeastern, and eastern quadrants of the governorate a manifestation of favorable physical geography, abundant hydrological assets, and intensive agricultural specialization. Conversely, sparse vegetation categories and bare lands dominated the southern and western landscapes, triggered by limited water availability and intensified seasonal aridity.

Vegetation change detection metrics confirm that the "stability" category occupied the largest proportion of the governorate's surface area at 48.86%. This underscores the resilience of baseline ecological characteristics across vast natural and agricultural terrains within the study area. In contrast, zones characterized by vegetation degradation accounted for 28.93%, outstripping the vegetation increase category, which stood at 22.21%. This imbalance indicates that substantial portions of the governorate were subjected to cumulative anthropogenic and environmental stressors, inducing canopy thinning and vegetative loss throughout the studied timeframe.

Crucially, the spatial correlation map between urban sprawl and vegetation dynamics verifies a direct spatial interlocking between built-up growth zones and areas of vegetative decline. The category of "urban expansion coupled with vegetation degradation" recorded the highest footprint, swallowing 22.27% of the total governorate area. This statistical predominance designates urban expansion as the primary driver behind green space contraction, forcing the conversion of fertile agricultural tracts and vegetated buffer zones into diversified built-up infrastructure, particularly along the fringes of Kirkuk District and flanking the arterial highways radiating toward Al-Dibs, Daquq, and Al-Hawija districts.

Conversely, the category of "urban expansion simultaneous with vegetation increase" registered the lowest footprint at a mere 2.09\%. This marginal share underscores the historical deficiency in integrating sustainable urban planning paradigms and reflects a structural lag in cultivating urban green infrastructure alongside physical construction. Finally, the analysis shows that 20.11% of the governorate exhibited a vegetation increase independent of urban growth, a trend attributed to localized agricultural optimization and advanced irrigation water management in rural zones.

Conclusions

1. The study demonstrates that Kirkuk Governorate experienced significant urban expansion during the 2000–2025 period, primarily nucleated within the center of Kirkuk District and along major transportation corridors, leading to the proliferation of built-up areas and shifting land use patterns.

2. Normalized Difference Vegetation Index (NDVI) analysis reveals a profound spatial disparity in green cover distribution; the highest canopy density was strictly concentrated within the northern and northeastern quadrants, whereas vegetative density sharply declined in the western and southern sectors of the governorate.
3. Vegetation change detection outcomes indicate that degradation zones encompassed 28.93\% of the total governorate area, compared to 22.21\% for vegetation increase and 48.86\% for stable zones, reflecting the cumulative footprint of anthropogenic and physical drivers in reshaping the environmental landscape.
4. The analysis verifies a distinct inverse spatial correlation between urban growth and vegetation cover; urban sprawl zones intersected precisely with sectors experiencing the highest rates of vegetative loss, with the category of "urban expansion coupled with vegetation degradation" alone swallowing 22.27\% of the total governorate area.

Recommendations:

1. Adopt sustainable urban planning paradigms to mitigate unregulated urban sprawl, while channeling future physical construction toward zones with minimal ecological impact on natural resources and green cover.
2. Safeguard fertile agricultural lands and green fields from built-up land-use transitions by enforcing strict zoning regulations and strengthening municipal planning oversight.
3. Expand afforestation initiatives and urban green infrastructure within primary city centers and sectors highly impacted by urban growth to counteract local environmental degradation.
4. Institutionalize remote sensing (RS) techniques and geographic information systems (GIS) for the systematic, periodic monitoring of spatiotemporal urban and environmental dynamics to support decision-makers and promote sustainable development within Kirkuk Governorate.

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