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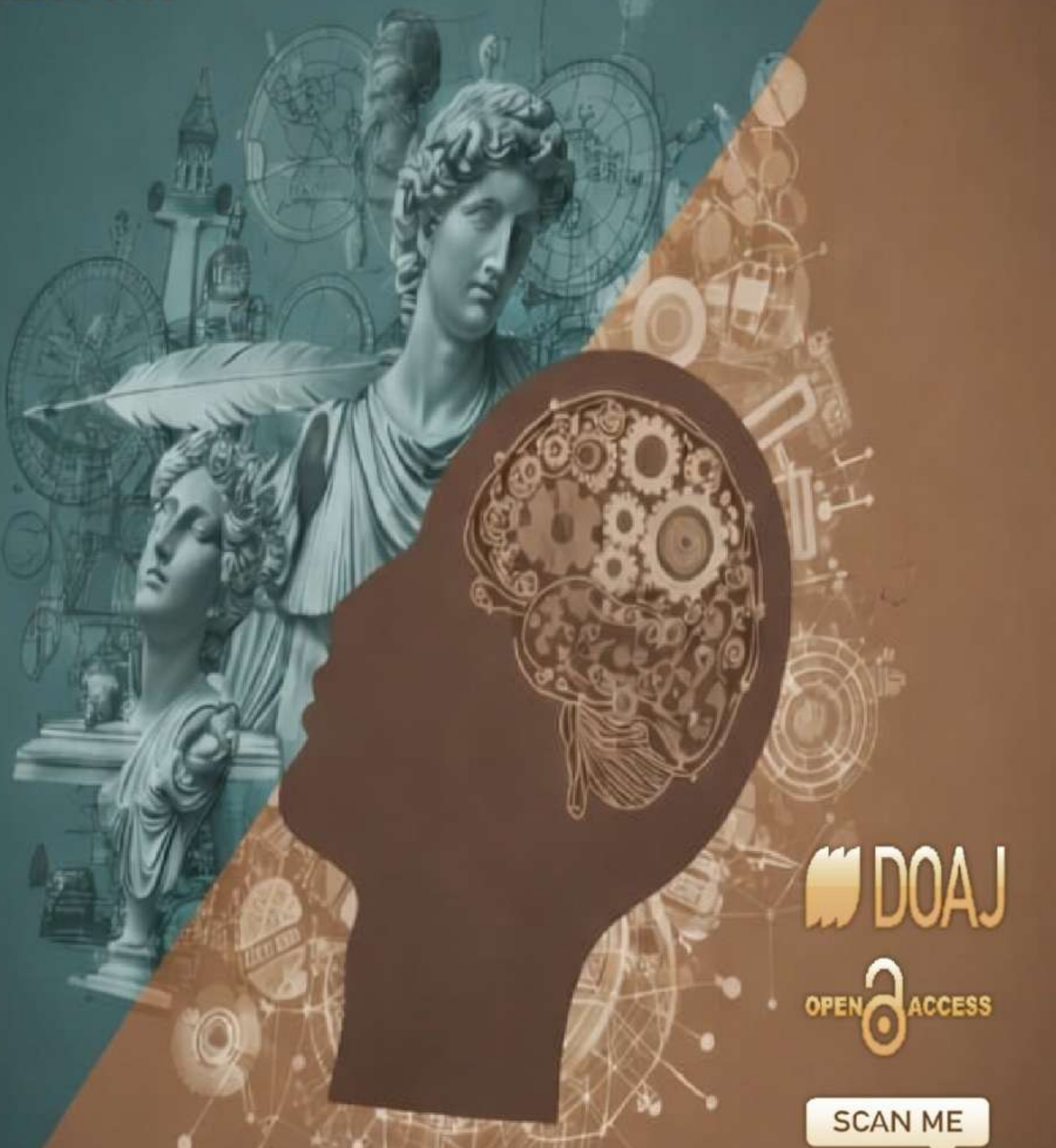

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بسم الله الرحمن الرحيم

افتتاحية العدد

الحمد لله رب العالمين، والصلاة والسلام على خاتم النبيين سيدنا محمد، وعلى آله وصحبه أجمعين

وبعد...

احبتنا الباحثين حول العالم... نضع بين أيديكم العدد الرابع من مجلتنا (مجلة جامعة الأنبار للعلوم الإنسانية) تلك المجلة الفصلية العلمية المحكمة والتي عن جامعة الانبار والتي تحمل بين ثناياها ١٣ بحثاً علمياً يضم تخصصات المجلة ولمختلف الباحثين من داخل العراق وخارجه ومن مختلف الجامعات.

في هذه البحوث العلمية، نرى جهداً علمياً مميزاً كان مدعاة لنا في هيئة التحرير ان نفخر به وان تلقى هذه البحوث طريقها الى النشر بعد ان تم تحكيمها من أساتذة أكفاء كل في مجال اختصاصه ليتم إخراجها في نهاية المطاف بهذا الشكل العلمي الباهر، والصورة الطيبة الجميلة، والجوهر العلمي الرصين، فجزى الله الجميع خير الجزاء لما أنتجته قرائحهم العلمية والثقافية وسطرته أقلامهم لينتفع ببحوث هذه المجلة والذخيرة العلمية المعروضة فيها كل القارئين من باحثين وطلبة ومهتمين.

إن العطاء الثر من الباحثين والجهد المعطاء من رئيس وأعضاء هيئة التحرير والدعم الكبير من رئاسة جامعة الانبار، وعمادة كلية التربية للعلوم الإنسانية يحث الخطو بنا للوصول إلى الغاية المرجوة المنشودة في دخول مجلتنا ضمن المستوعبات العالمية للنشر العلمي. لذا وجب التنويه بأننا بصدد التحديث المستمر والمتواصل لشروط النشر وآليته للارتقاء بأعداد مجلتنا والوصول بها إلى مكانة علمية أرقى وأسمى تضاهي المجلات العلمية ذات المستويات المتقدمة، ولتساهم بفاعلية في حركة النشر والبحث العلمي العربي سعيا لتعزيز مكانة البحث العلمي وتوسيع آفاقه في البلدان العربية لأن البحث العلمي كان وما يزال واحدا من عوامل رقي الأمم ومؤشرا على تقدمها... ومن الله التوفيق

أ.د. فؤاد محمد فريح

رئيس هيئة التحرير

تعليمات النشر في مجلة جامعة الأنبار للعلوم الإنسانية

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- يقدم الباحث خطابا مرافقا يفيد ان البحث او ما يشابهه لم يسبق نشره، ولم يقدم لأي جهة اخرى داخل العراق او خارجه، ولحين انتهاء اجراءات البحث.
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- يكون البحث مكتوبا بلغة سليمة باللغة العربية او اللغة الانكليزية ومطبوع على الالة الحاسبة بخط Simplified Arabic حجم ١٤، على ان يتم تمييز العناوين الرئيسة والفرعية.
- تكتب الهوامش والمراجع وفق نظام APA للتوثيق، بخط حجم ١٤، على ان يتم ترتيبها بالتتابع كما وردت في المتن، ويكون تنظيم المراجع هجائياً حسب المنهجية العلمية المعتمدة وباللغتين العربية والانكليزية.
- تؤول كافة حقوق النشر الى المجلة.
- تعبر البحوث عن اراء مؤلفيها، ولا تعبر بالضرورة عن راي المجلة.
- **بيانات الباحث والملخص:**
- يلزم الباحث بتقديم البيانات الخاصة به وببحثه، وباللغتين العربية والانكليزية، وتشمل الاتي: عنوان البحث، أسماء وعناوين الباحثين، ورقم الهاتف النقال، والبريد الالكتروني، وملخصين – عربي وانكليزي – بحد ادنى ٢٥٠ كلمة يحتويان الكلمات المفتاحية للبحث، والهدف من البحث، والمنهج المتبع بالبحث، وفحوى النتائج التي توصل اليها.
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- اذا تضمن البحث جداول او اشكال يفضل ان لا يزيد عرضها عن حجم الصفحة A 4، على ان تطبع ضمن المتن.
- يوضع الشكل بعد الفقرة التي يشار اليه فيها مباشرة، ويكون عنوانه في اسفله.
- يوضع الجدول بعد الفقرة التي يشار اليه فيها مباشرة، ويكون عنوانه في اعلاه.
- **تقويم البحوث:**
- تخضع جميع البحوث المرسلة الى المجلة الى فحص اولي من قبل هيئة التحرير لتقرير اهليتها للتحكيم، ويحق لها ان تعتذر عن قبول البحث دون بيان الاسباب.
- جميع عمليات تقويم البحوث الى نظام التعمية المزدوجة لضمان رصانة البحوث والابتعاد عن تضارب المصالح.

- تخضع جميع البحوث للتقويم العلمي بما يضمن رصانتها العلمية، وقد يطلب من الباحث اذا اقتضى الامر مراجعة بحثه لإجراء تعديلات عليه.
- **الوصول المفتوح:**
- متاحة جميع البحوث على موقع المجلة الالكتروني وموقع المجلات الاكاديمية العراقية ضمن سياسة الوصول المفتوح.
- **اجور النشر:**
- يقوم الباحث بتسديد اجور النشر، والبالغة ١٥٠،٠٠٠ مائة وخمسة وعشرون الف دينار عراقي للبحوث باللغة العربية، و٧٥.٠٠٠ خمسة وسبعون الف دينار للبحوث باللغة الانكليزية، واذا زادت صفحات البحث عن ٢٥ صفحة تضاف ٥،٠٠٠ خمسة الاف دينار عراقي عن كل صفحة.
- الباحثون من خارج العراق تنشر نتاجاتهم العلمية مجانا.
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فهرست البحوث المنشورة

بحوث العلوم التربوية والنفسية

بحوث الجغرافية

بحوث التاريخ

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Quantifying Four Decades of Urban Expansion and Densification in Erbil Governorate Using the Global Human Settlement Layer (GHS-BUILT-S)

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A B S T R A C T

Aims: This study aims to analyze the urban transformations witnessed in the city of Erbil over the period (1980–2025), with a focus on measuring patterns of urban expansion and tracking the evolution of urban density. The study seeks to employ built-up surface data derived from the Global Human Settlement Layer (GHS-BUILT-S) product to identify spatiotemporal changes in built-up surface ratios at high spatial resolution, understand the relationship between population growth and urban land use transformations, and assess urban development trends and their spatial and temporal implications. ***Methods***: The study relied on analyzing built-up surface data extracted from the GHS-BUILT-S dataset (R2023A), which provides a continuous measurement of built-up surface percentage at a spatial resolution of 100 meters. Data were retrieved for eleven temporal epochs (from 1980 to 2025) and processed using the Google Earth Engine platform for image analysis and preparation. Subsequently, the extracted values were reclassified into five categories according to built-up intensity (from very low to very high density). Statistical analyses were conducted using MATLAB software to measure temporal trends and spatial patterns of urban expansion. ***Results***: The results revealed a clear and consistent increase in built-up areas in Erbil, with a gradual transition from low-density development patterns (0–25%) to high-density development patterns (exceeding 50%), particularly after 2000. The highest density category (75–100%) increased more than fivefold, while areas of very low density declined significantly. Statistical analysis revealed a strong negative correlation (r = -0.85) between population and low-density built-up areas, while a strong positive correlation (r = 0.82) emerged between population and high-density built-up areas. These findings indicate that demographic pressures and economic growth serve as primary drivers of both horizontal expansion and increased urban density. The study also demonstrated that Erbil's growth passed through two main phases: the first,

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before 2000, characterized by low-density horizontal expansion, and the second, after 2000, witnessing a remarkable increase in urban density due to improved economic stability and growing investments. ***Conclusions***: The study concludes that utilizing long-term, high-resolution built-up surface data is crucial for tracking urban changes and analyzing their patterns, as it provides deep insights into the relationship between population dynamics and spatial transformations. The findings confirm that urban planning in rapidly growing cities like Erbil requires integrated strategies that account for both horizontal expansion and density increase. The study recommends integrating these methodologies into sustainable urban planning processes to ensure a balanced urban future.

Keywords: Urbanization, Urban Expansion, Urban Density, Erbil, GHSL, Remote Sensing, Google Earth Engine.

قياس أربعة عقود من التوسع والتكثيف الحضريين في محافظة أربيل باستخدام طبقة المستوطنات البشرية العالمية (GHS-BUILT-S)

م.م. مصطفى صالح اسماعيل

جامعة صلاح الدين- كلية الآداب –اربيل-العراق

الملخص:

الأهداف: تهدف هذه الدراسة إلى تحليل التحولات العمرانية التي شهدتها مدينة أربيل خلال الفترة (١٩٨٠–٢٠٢٥)، مع التركيز على قياس أنماط التوسع الحضري وتتبع تطور الكثافة العمرانية. وتسعى الدراسة إلى توظيف بيانات السطوح المبنية المستمدة من منتج Global Human Settlement Layer (GHS-BUILT-S) بهدف تحديد التغيرات الزمانية المكانية في نسب السطوح المبنية بدقة مكانية عالية، وفهم العلاقة بين النمو السكاني والتحولات في استخدامات الأرض الحضرية، فضلاً عن تقييم اتجاهات التنمية الحضرية وتأثيراتها المكانية والزمانية. ***المنهجية***: اعتمدت الدراسة على تحليل بيانات السطوح المبنية المستخرجة من مجموعة بيانات) GHS-BUILT-Sالإصدار ٢٠٢٣A)، والتي توفر قياساً متصلاً لنسبة السطح المبني بدقة مكانية تبلغ ١٠٠ متر. تم استخلاص البيانات لأحد عشر مقطعاً زمنياً (من ١٩٨٠ إلى ٢٠٢٥) ومعالجتها باستخدام منصة Google Earth Engine لتحليل المرئيات الفضائية وإعدادها للتحليل. بعد ذلك، أعيد تصنيف القيم المستخلصة إلى خمس فئات وفقاً لشدة البناء (من منخفض الشدة إلى عالي الشدة). ولتحليل الاتجاهات الزمنية والأنماط المكانية للتوسع العمراني، أُجريت المعالجات الإحصائية باستخدام برنامج MATLAB. ***النتائج***: أظهرت النتائج زيادة واضحة ومطردة في المساحات المبنية بمدينة أربيل، مع انتقال تدريجي من أنماط التنمية منخفضة الكثافة (٠–٢٥%) إلى أنماط التنمية عالية الكثافة (أكثر من ٥٠%)، ولا سيما بعد عام ٢٠٠٠. وسجلت الفئة الأعلى كثافة (٧٥–١٠٠%) زيادة تجاوزت الخمسة أضعاف، في حين شهدت المناطق ذات الكثافة

المنخفضة جداً تراجعاً ملحوظاً. وكشف التحليل الإحصائي عن وجود علاقة ارتباط سلبية قوية (r = -0.85) بين عدد السكان والمساحات المبنية منخفضة الشدة، في المقابل، ظهرت علاقة ارتباط إيجابية قوية (r = 0.82) بين عدد السكان والمساحات المبنية عالية الشدة. وتشير هذه النتائج إلى أن الضغوط الديموغرافية والنمو الاقتصادي يشكلان محركين رئيسيين لكل من التوسع الأفقي وزيادة الكثافة العمرانية. كما بيّنت الدراسة أن نمو مدينة أربيل مر بمرحلتين رئيسيتين: الأولى قبل عام ٢٠٠٠ تميزت بالتوسع الأفقي منخفض الكثافة، والثانية بعد عام ٢٠٠٠ شهدت قفزة نوعية في الكثافة العمرانية بفضل تحسن الاستقرار الاقتصادي وتزايد الاستثمارات. ***الاستنتاجات***: تخلص الدراسة إلى أهمية توظيف بيانات السطوح المبنية طويلة المدى عالية الدقة في تتبع التغيرات الحضرية وتحليل أنماطها، لما توفره من فهم عميق للعلاقة بين الديناميكيات السكانية والتحولات المكانية. وتؤكد النتائج أن التخطيط الحضري في المدن سريعة النمو كأربيل يحتاج إلى استراتيجيات متكاملة تأخذ في الاعتبار كل من التوسع الأفقي وزيادة الكثافة. وتوصي الدراسة بدمج هذه المنهجيات في عمليات التخطيط الحضري المستدام لضمان مستقبل عمراني متوازن.

الكلمات المفتاحية: التحضر، التوسع العمراني، الكثافة العمرانية، أربيل، GHSL، الاستشعار عن بعد، Google Earth Engine.

1. Introduction

Erbil Governorate, located in the Kurdistan Region of Iraq, has experienced a remarkable transformation over the past four decades. Once a modestly sized provincial capital, Erbil has expanded rapidly into a metropolitan hub, driven by population growth, economic development, and regional stability (Mustafa et al., 2020; Mansour, 2019). The city's built-up area has expanded significantly since the 1980s, extending well beyond its historic core to incorporate surrounding towns and agricultural lands. This expansion has been accompanied by profound changes in the urban fabric, including the emergence of high-density residential and commercial zones, sprawling peri-urban districts, and an increasingly complex spatial structure. As one of the fastest-growing cities in post-2003 Iraq, Erbil offers a compelling case for analysing the spatial and temporal dynamics of urban growth under conditions of socio-economic transition.

Monitoring such urban expansion is crucial for sustainable land-use planning and infrastructure management. Traditionally, urban growth has been studied through land-cover classification approaches that distinguish discrete categories such as "urban," "agriculture," or "water" (Herold et al., 2003;

Schneider et al., 2010). While these categorical maps provide valuable information on spatial extent, they are limited in their ability to capture gradual changes in settlement intensity or the internal heterogeneity of urban areas. Conventional classification methods typically rely on threshold-based or supervised algorithms that assign each pixel to a single class, often resulting in misclassification of mixed or transitional land covers (Seto et al., 2012). Moreover, inconsistencies in sensor data, classification schemes, and preprocessing across time make it difficult to conduct long-term, cross-temporal analyses with high reliability (Jat et al., 2008). As a result, much of the previous research on urbanisation has focused on the expansion of urban boundaries, while neglecting the equally important process of urban densification within already developed zones.

To overcome these limitations, recent advances in global remote sensing have produced datasets that represent urban characteristics in a continuous rather than categorical form. Among these, the Global Human Settlement Layer – Built-up Surface (GHS-BUILT-S) dataset provides a breakthrough in measuring urbanisation intensity. Developed by the European Commission's Joint Research Centre, GHS-BUILT-S quantifies the proportion of built-up surface per 100 m × 100 m pixel for multiple epochs from 1975 to 2030 (Pesaresi et al., 2023). Unlike traditional land-cover maps, this continuous dataset captures the degree of built-up coverage within each pixel, ranging from sparsely developed peri-urban zones to fully built-up urban cores, allowing researchers to assess not only the spatial expansion of cities but also their internal densification. The dataset's harmonised, machine-learning-based processing of Landsat and Sentinel imagery ensures temporal consistency and comparability across decades, making it particularly suitable for studying long-term urban transitions (Pesaresi et al., 2023).

The present study applies this novel dataset to characterise and quantify urban expansion and densification in Erbil Governorate from 1980 to 2025. By leveraging the continuous built-up surface estimates from GHS-BUILT-S within the Google Earth Engine (GEE) environment, we developed a reproducible workflow for extracting, reclassifying, and statistically analysing built-up intensity across multiple time steps. The analysis focuses on two complementary dimensions of urbanisation: the horizontal expansion of built-up land and the vertical intensification of existing urban cores. Unlike previous studies based on binary classification, this research employs a continuous measure of built-up proportion, offering a more nuanced understanding of Erbil's urban evolution. In doing so, it provides one of the first high-resolution, temporally consistent assessments of long-term urban dynamics in the region, linking population growth, spatial expansion, and densification within a unified analytical framework.

2. Materials and Methods

2.1 Study Area

This study focuses on the Erbil Governorate, located in northern Iraq, between approximately 35°30′–37°10′N and 43°20′–45°10′E. The region encompasses a diverse topography, ranging from the Zagros Mountains in the northeast to the lowland plains in the southwest. Erbil is characterised by a semi-arid to Mediterranean climate, with annual precipitation ranging from 300 to 700 mm and summer temperatures often exceeding 40 °C. The area has undergone substantial urban expansion over the past five decades, driven by population growth and economic development. For the spatial analysis, district boundaries including Erbil, Shaqlawa, Soran, Koya, Mergasur, Makhmur, and Choman were delineated using administrative shape files in ArcGIS Pro. These boundaries served as the study mask for all image processing and temporal analyses (Fig. 1).

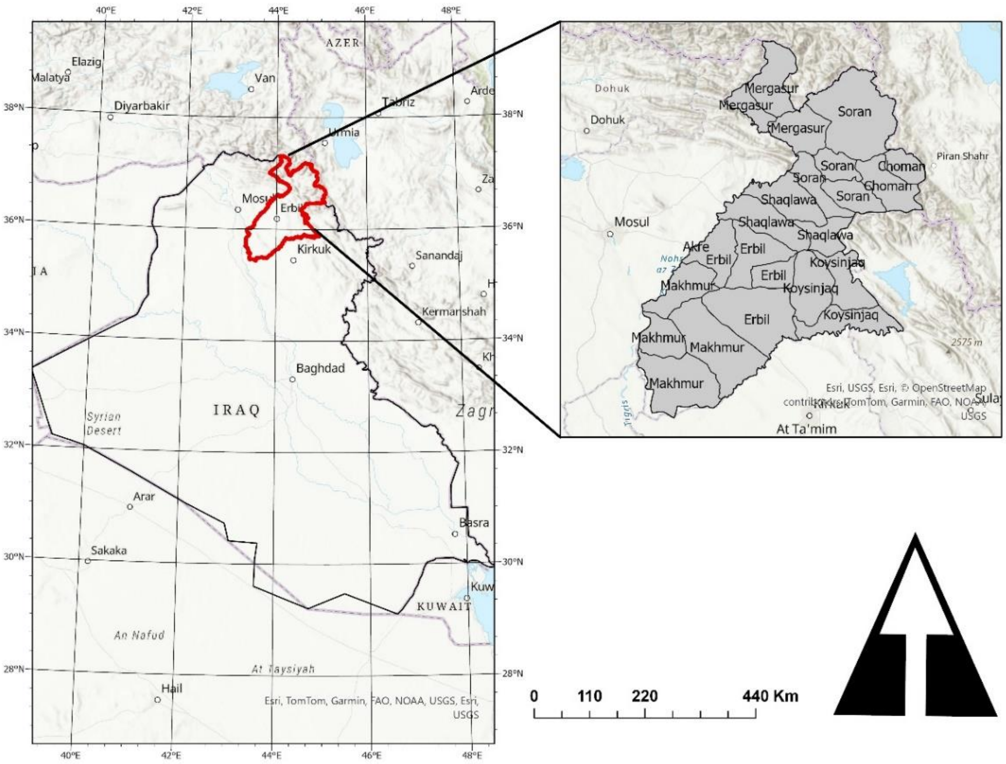

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Figure 1. Location of the study area in northern Iraq, showing the Erbil Governorate outlined in red. The inset map illustrates district boundaries, including Erbil, Shaqlawa, Soran, Koya, Mergasur, Makhmur, and Choman.

2.2 Data

To quantify urban expansion, we used the Global Human Settlement Layer built-up surface product (GHS-BUILT-S, release 2023A). This dataset, developed by the European Commission's Joint Research Centre, provides globally consistent estimates of built-up surface area at 100 m spatial resolution for multiple epochs between 1980 and 2030. Unlike conventional land-cover classifications that assign each pixel to a discrete class (e.g. "urban", "agriculture", "water"), GHS-BUILT-S is a continuous built-up surface layer. For every pixel, the product reports the estimated built-up area in square meters, which can be expressed as a proportion (%) of the 100 m grid cell. This enables a more nuanced representation of settlement intensity, from sparsely built peri-urban areas to highly compact urban cores, rather than a simple binary built-up/non-built-up label.

The built-up surface estimates are derived from time series of medium-resolution satellite imagery (primarily Landsat for the historical period and Sentinel-2 for recent years), combined with ancillary data and machine-learning-based image classification and post-processing workflows. A harmonised and internally consistent methodology is applied to all epochs, which makes GHS-BUILT-S particularly suitable for long-term change analysis. In this study, we accessed the product through the Google Earth Engine (GEE) data catalogue (JRC/GHSL/P2023A/GHS_BUILT_S), which enabled direct server-side processing, clipping to the Erbil study area, and export of the built-up surface band for further analysis. We analysed the built-up surface for the years 1980, 1985, 1990, 1995, 2000, 2005, 2010, 2015, 2020, and 2025. These eleven steps outline the major phases of urban development in Erbil and its surrounding areas. The continuous nature of the GHSL built-up metric allowed us not only to map the spatial extent of urban areas but also to quantify changes in urban intensity and densification within already developed zones over time.

2.3 Image Processing and Export

All preprocessing and data extraction were implemented in GEE using the JRC/GHSL/P2023A/GHS_BUILT_S collection. The workflow (Fig. 2) comprised the following sequential steps:

1. Study area preparation: The Erbil boundary shapefile was imported as a FeatureCollection and converted to a geometry object (studyArea).
2. Image loading: For each target year, the built-up surface band (built_surface) was selected and clipped to the study area.
3. Export: Each clipped image was exported as a GeoTIFF to Google Drive using a 100 m pixel size in the EPSG:3857 projection, to remain consistent with the native GHS-BUILT-S projection and the default projection used in GEE.
4. Visualisation: Built-up density maps for selected years (e.g., 1980 and 2025) were visualised using a grayscale palette (min = 0, max = 8000) to highlight the progressive increase in urban coverage.

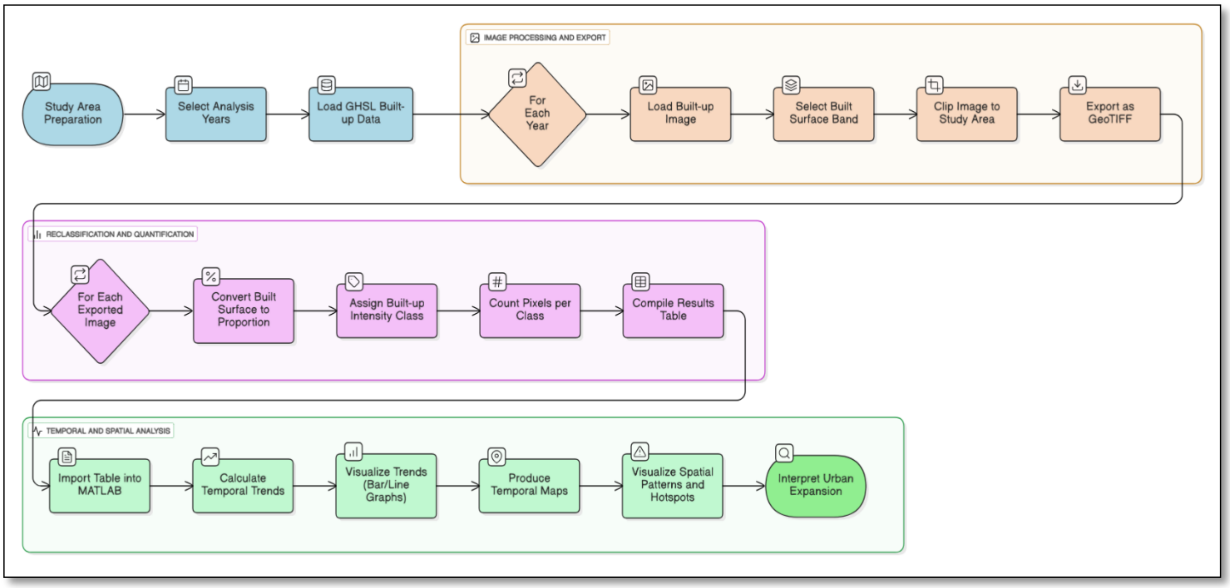


Figure 2. Workflow illustrating the data acquisition, reclassification, quantification, and temporal analysis steps implemented in GEE and MATLAB.

2.4 Reclassification and Quantification

To facilitate interpretation of the continuous GHSL built-up surface layer and to enable comparison of urban development stages through time, each exported GeoTIFF was reclassified into discrete built-up intensity classes. First, the original built-up surface values (m^2 of built-up area per 100 m pixel) were converted to the proportion of built-up surface (%) by dividing by the pixel area (10,000 m^2) and multiplying by 100. This produced a continuous variable ranging from 0 (no built-up surface) to 100 (fully built-up pixel). Based on this proportional measure, we defined five ordered intensity classes representing a gradient from very low to very high levels of urbanisation (Table 1). The class boundaries were chosen in 20% increments to (i) retain sensitivity to differences in settlement density, while (ii) keeping the number of categories small enough for robust temporal and spatial comparisons. Pixels with <20% built-up proportion were considered very low-intensity or emerging development, whereas pixels with >80% built-up proportion represented highly compact, fully urbanised areas.

For each time step, the reclassified raster was converted to frequency statistics, and pixel counts per class were calculated for the entire Erbil Governorate as well as for each administrative district. These counts were then converted to area (km²) by multiplying by the pixel area and summarized in a temporal table. The resulting table provides, for every year and district, the total area occupied by each built-up intensity class and the relative share (%) of the study area. This dataset formed the basis for subsequent analyses of (i) changes in the spatial extent of built-up land, (ii) shifts in the distribution of built-up intensity (e.g. infilling vs. outward expansion), and (iii) identification of periods of accelerated urban growth.

Table 1. Built-up intensity classes derived from the GHSL built-up surface proportion for each 100 m pixel.

Class ID	Built-up proportion (%)	Description
1	0–20	Very low built-up
2	20–40	Low built-up
3	40–60	Moderate built-up
4	60–80	High built-up
5	80–100	Very high built-up

2.5 Temporal and Spatial Analysis

The compiled results were imported into MATLAB R2023a for quantitative analysis. Temporal trends in urban growth were examined by calculating the annual and decadal rates of change in built-up proportion across the study area and its administrative districts. Linear and polynomial regression models were used to assess the growth trajectory, while R^2 and RMSE statistics were employed to quantify the model fit.

To visualise spatiotemporal dynamics, temporal maps and trend graphs (bar and line plots) were produced. Additionally, spatial autocorrelation (Moran's I) and hotspot analysis were performed to identify clusters of high-intensity urban growth. Interpretation of these patterns enabled the identification of urban expansion fronts, infilling trends, and peri-urban sprawl within the Erbil metropolitan region.

2.6 Statistical Analysis

The statistical analysis was designed to link the reclassified built-up intensity data with both temporal dynamics and spatial patterns of urban growth. First, for each year and each built-up intensity class, the total built-up area (km^2) was calculated at the level of the entire Erbil Governorate and for individual districts. These time series were then used to estimate long-term trends by fitting ordinary least squares linear regression models, with built-up area as the dependent variable and year as the predictor. The regression slope (km^2 $year^{-1}$) provided a quantitative measure of the rate and direction of change for each intensity class, while the coefficient of determination (R^2) and associated p-values were used to assess goodness of fit and statistical significance. To capture changes in the internal structure of the urban fabric, we quantified densification by tracking the relative change (%) in the area occupied by high-intensity built-up classes (Classes 4 and 5). This metric reflects the transition from low- and medium-intensity development to more compact, highly urbanised zones, and allowed us to distinguish between outward expansion and in situ infilling of existing urban areas. In a second step, we examined the relationship between urban growth and demographic change explicitly. Historical population estimates for Erbil Governorate were obtained from the Mongabay population database (https://books.mongabay.com/population_estimates/full/Arbil-Iraq.html) for the same observation years used in the GHSL analysis. Pearson's correlation coefficients (r) were calculated between total population and built-up area for the lowest (0–25 %) and highest (75–100 %) intensity classes to assess how population growth relates to the loss of sparsely built land and the expansion of dense urban cores. In addition, a bivariate time-series plot with dual y-axes was produced to visualise the co-evolution of population and high-intensity built-up area over time (Fig. 6). All statistical computations and visualisations were conducted in MATLAB R2023a, following a reproducible workflow in which Google Earth Engine exports were transformed into matrix-based datasets for regression, densification metrics, correlation analysis, and figure generation.

3. Results

3.1 Spatial and Temporal Dynamics of Built-up Surfaces

The spatiotemporal maps derived from the GHSL built-up surface product reveal a clear and progressive expansion of urban areas within Erbil Governorate between 1980 and 2025 (Fig. 3). In 1980, built-up surfaces were concentrated around the Erbil city core, with sparse, low-intensity development spreading radially along major transport corridors. Subsequent decades show an outward expansion pattern characterised by increasing connectivity among surrounding settlements. By 2010, several secondary built-up clusters had emerged, particularly toward Shaqlawa and Koya districts. The 2025 projection indicates extensive urban coalescence, where formerly peripheral settlements are now part of a contiguous metropolitan zone. The continuous GHSL metric not only delineates urban extent but also assesses the intensity of urbanisation. The maps show a transition from predominantly low built-up proportions (<25%) in the 1980s toward higher intensity classes (>50%) in more recent decades. This densification trend is particularly visible in the central and northeastern sectors of Erbil city, where impervious surfaces have expanded significantly since 2000.

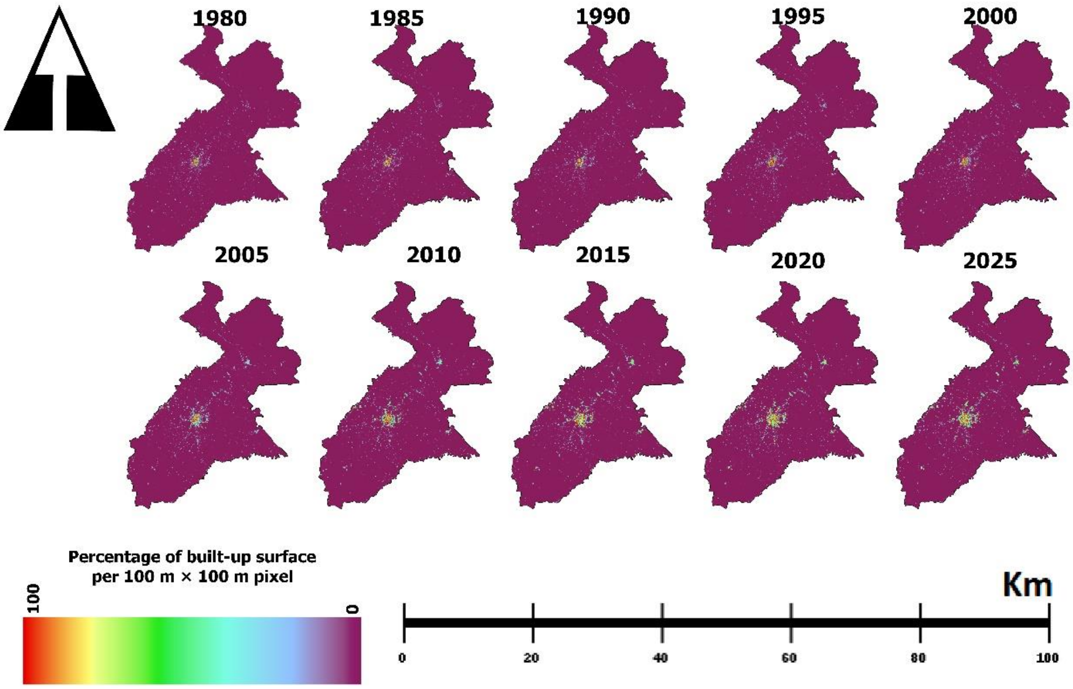
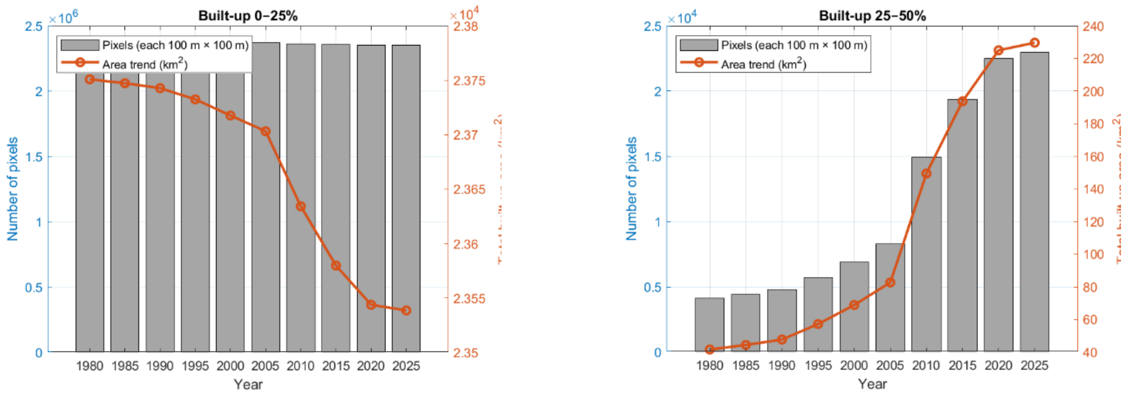


Figure 3. Spatiotemporal distribution of built-up surfaces in Erbil Governorate from 1980 to 2025, derived from GHSL (100 m resolution). The colour scale represents the percentage of built-up surface per 100 m × 100 m pixel.

3.2 Temporal Changes Across Built-up Intensity Classes

Built-up change was quantified using both the number of built-up pixels in each intensity class (pixel counts) and the corresponding built-up area in km², assuming that each 100 m × 100 m pixel represents 0.01 km². In the paragraphs below, we report the results in terms of built-up area (km²). Quantitative analysis of built-up surface proportions demonstrates clear temporal change across all intensity classes, with distinct dynamics among them (Fig. 4). In Erbil Governorate, the very low built-up class (0–25%) shows a slight but consistent decline, from approximately 23,760 km² in 1980 to about 23,550 km² in 2025, reflecting the gradual conversion of previously undeveloped or sparsely developed land into higher-intensity built-up categories.

In contrast, the 25–50% and 50–75% classes show a steep and sustained increase from the mid-1990s onward, with the largest acceleration observed between 2005 and 2015. The 25–50% class grew from less than 60 km² in 1980 to over 220 km² by 2025, while the 50–75% class expanded fivefold during the same period. The highest intensity class (75–100%), representing fully urbanised surfaces, increased modestly until 2000 and then rose sharply, reaching more than 2 km² in 2025.



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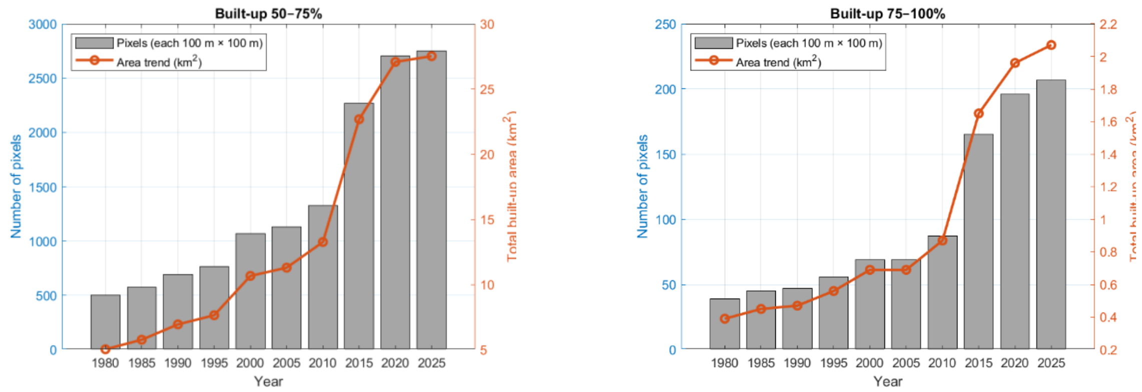

Figure 4. Temporal trends of built-up area by intensity class from 1980–2025. Bars represent the number of built-up pixels (each 100 m × 100 m), and the orange line indicates the corresponding total built-up area (km²).

3.3 Relationship Between Population Growth and Built-up Expansion

A strong relationship was observed between population growth and the expansion of built-up land, particularly for high-intensity classes (Fig. 5 and Fig. 6). The correlation between population and the very low built-up class (0–25%) was strongly negative (r = –0.85, R^2 = 0.72), reflecting the steady decline of undeveloped land as population increased. Conversely, the very high built-up class (75–100%) exhibited a strong positive correlation with population (r = 0.82, R^2 = 0.68), indicating that urban densification closely tracked demographic growth.

The temporal comparison (Fig. 6) further illustrates this relationship: as Erbil's population increased from below 0.5 million in 1980 to over 2 million in 2020, the corresponding area of high-intensity built-up land expanded from approximately 0.4 km² to nearly 2 km². This synchronous increase suggests that population pressure has been a primary driver of both urban sprawl and densification in the region.

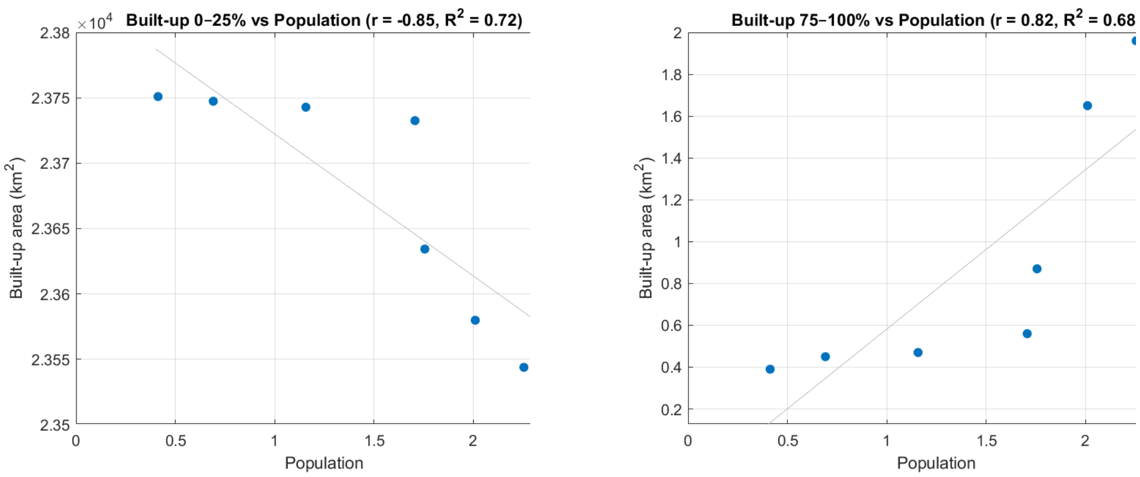

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Figure 5. Relationships between population and built-up area for low (0–25%) and high (75–100%) intensity classes, showing negative and positive correlations, respectively.

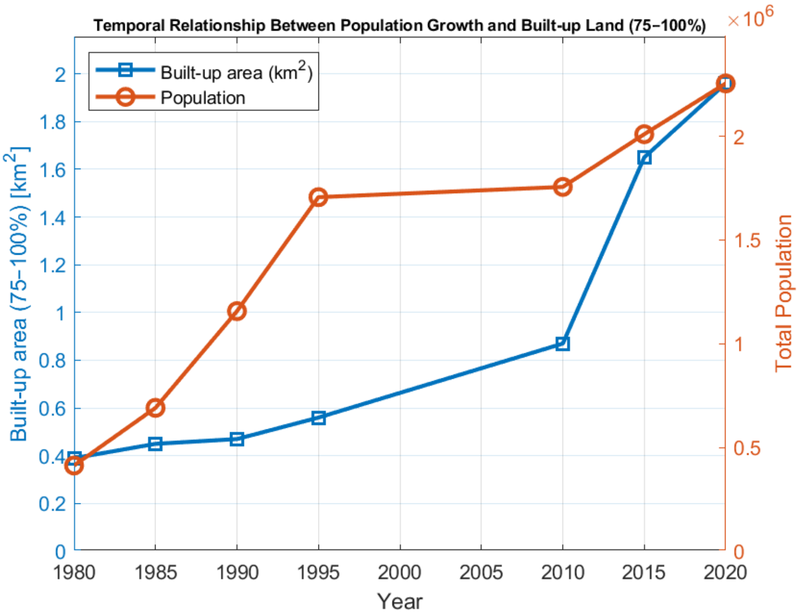

Figure 6. Temporal comparison of population growth and high-intensity (75–100%) built-up land from 1980 to 2020 in Erbil Governorate.

4. Discussion and conclusion

The findings of this study reveal a clear and sustained transformation of the urban landscape in Erbil Governorate between 1980 and 2025. Built-up land expanded considerably during this period, with a marked transition from low-intensity (0–25%) to higher-intensity classes (>50%), especially after 2000 (Figs. 3–4). The highest intensity category (75–100 %) increased more than fivefold, while the very low built-up class declined substantially. These shifts align with the region's demographic growth: a strong negative correlation (r = –0.85) between population and the 0–25 % class, and a positive correlation (r = 0.82) between population and the 75–100 % class, indicate that population growth has been a key driver of urban expansion (Figs. 5–6). Collectively, the evidence points to a two-phase urbanisation trajectory: an early stage of extensive, low-density growth prior to 2000, followed by a rapid densification phase thereafter.

A major strength of this work lies in its use of the Global Human Settlement Layer built-up surface dataset (GHS-BUILT-S, R2023A), which differs fundamentally from

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conventional land-cover classification products. Instead of assigning each pixel to a binary "urban" or "non-urban" category, GHS-BUILT-S quantifies the proportion of built-up surface per 100 m × 100 m grid cell, providing a continuous measure of urban intensity (Pesaresi et al., 2023). This enables a more nuanced characterisation of settlement morphology and allows detection of gradual changes in density that would be invisible in categorical datasets. The dataset's temporal consistency, derived from harmonised Landsat and Sentinel imagery processed through machine learning, makes it particularly suitable for long-term, comparative urban studies (Pesaresi et al., 2023). Such data richness is crucial for understanding not only the extent but also the intensity and direction of urban change in rapidly evolving regions.

The observed relationship between population growth and built-up expansion is consistent with broader global evidence. Numerous studies demonstrate that demographic growth remains the dominant driver of urban land expansion, particularly during the early stages of urban development (Seto et al., 2011; Mahtta et al., 2022). A global analysis by Mahtta et al. (2022) of over 300 cities found that from 1970 to 2000, population growth accounted for the majority of urban land expansion, whereas after 2000, the influence of economic growth became increasingly significant. The patterns observed in Erbil mirror this trend: pre-2000 expansion was largely driven by population growth, while post-2000 growth reflects the additional influence of rising economic capacity and investment.

The two distinct phases identified in this study align closely with Erbil's socio-economic and political trajectory. During the pre-2000 period, the city expanded horizontally, characterised by the outward sprawl of low-density residential areas around the historic core. This stage corresponds with a period of significant population growth due to rural–urban migration and natural increase but limited economic diversification and infrastructural investment (Abdullah H., 2012). Low- and moderate-intensity built-up classes dominated the landscape, indicating fragmented and discontinuous settlement patterns typical of early urbanisation in developing regions (Seto et al., 2011).

Following 2000, a rapid densification phase emerged, coinciding with enhanced political stability and economic development in the Kurdistan Region of Iraq. After 2003, the region experienced relative safety compared with other parts of Iraq, attracting both internal migrants and foreign investment (Mansour, R., 2019). The enactment of new investment laws in 2006 stimulated large-scale construction projects, including high-rise residential and commercial developments in Erbil's central and peri-urban areas (Mustafa et al., 2020). GDP growth averaged around 8 % per year in the mid-2000s, driven primarily by oil revenues and real estate development (Gunter ., 2021). These conditions explain the surge in high-intensity built-up classes (60–100 %) after 2000, reflecting both horizontal expansion and vertical consolidation. The strong positive correlation between population and high-intensity built-up areas supports the interpretation that economic prosperity and regional stability jointly accelerated densification processes.

This evolution from extensive to intensive urban growth has important implications for sustainable urban planning. The early, low-density expansion phase typically results in inefficient land use, increased infrastructure costs, and loss of agricultural land (Angel et al., 2011). Conversely, the later densification phase can enhance spatial efficiency and reduce per-capita resource consumption if properly managed but may also lead to congestion and reduced green space if unplanned (UN-Habitat, 2020). The observed increase in high-density built-up areas in Erbil, therefore, underscores the need for compact-city planning strategies, including vertical development, mixed-use zoning, and transport-oriented planning, to balance growth with livability.

The continuous built-up surface data also highlights subtle transition dynamics that are often obscured in traditional classification maps. The gradual shift from 0–25% to higher-intensity classes represents the transformation of peri-urban zones into integrated urban areas, a process that reflects both socio-economic integration and infrastructure expansion (Fragkias et al., 2013). This pattern, consistent with global peri-urbanisation processes, suggests that Erbil's urban footprint is evolving toward a more cohesive metropolitan structure while still absorbing peripheral agricultural and open lands.

Despite the strengths of this approach, some limitations must be acknowledged. The 100 m resolution of GHSL data constrains the detection of fine-scale or informal developments, and automated classifications can misclassify mixed land covers or rapidly changing construction sites (Carioli et al., 2025). Moreover, while population and economic growth were the main drivers considered here, other factors, such as migration flows, land policy, and infrastructure planning- likely influenced the spatial patterns of urbanisation. Future research could incorporate these factors and validate GHSL-derived estimates with local cadastral and remote-sensing data at finer resolutions.

Overall, the results demonstrate that Erbil's urbanisation has followed a trajectory comparable to that of many cities in emerging economies: an initial population-driven expansion followed by economically enabled densification. The period after 2000 marked a decisive shift towards vertical growth, reflecting the combined effects of regional stability, investment inflows, and improved governance. By employing a continuous built-up surface dataset, this study provides a high-resolution, temporally consistent account of these dynamics, offering an analytical framework that can be extended to other rapidly urbanising regions to inform sustainable urban management and land-use policy.

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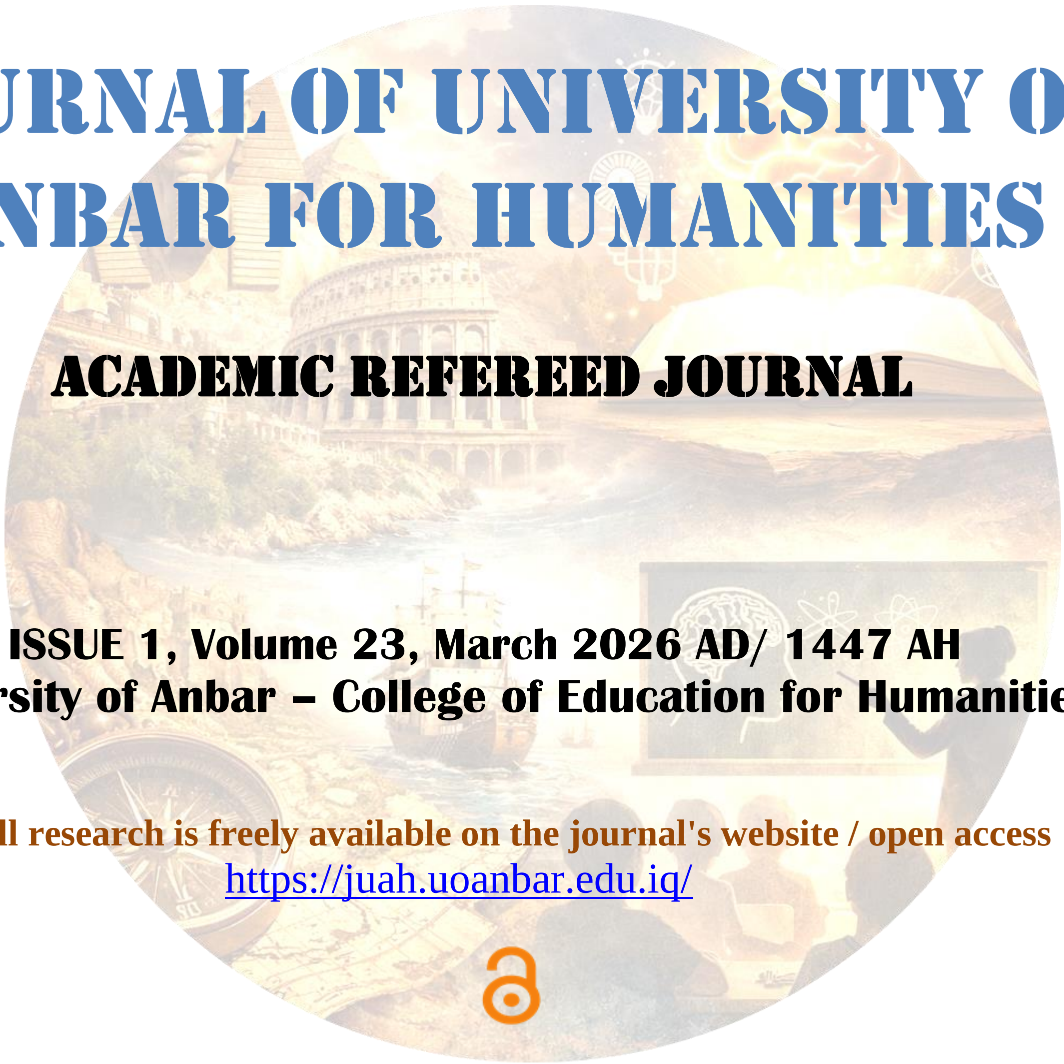

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In the name of God, the Most Gracious, The Most Merciful

Editorial of the issue

Praise be to God, Lord of the Worlds, and may blessings and peace be upon the Seal of the Prophets, our Master Muhammad, and upon all his family and companions.

Dear researchers around the globe, it is our pleasure to announce the first issue for the year 2026 of our scientific journal (Journal of University of Anbar for Humanities) (JUAH), the peer-reviewed quarterly scientific journal. This issue contains 13 scientific paper that include the journal's specialties for researchers from the University of Anbar and other Iraqi universities. It also contains international scientific papers. In these scientific research, you would find scientific effort that we in the editorial board should be proud of. These researches found its way to publication after being peer-reviewed by qualified professors, each in his field of specialization.

The generous contribution of researchers, the generous effort of the Editor in Chief and members of the Editorial Board, and the great support from the presidency of University Of Anbar and the deanship of College of Education for Humanities encourage us to take steps to reach the looked-for aim of indexing our journal in the largest abstract and citation database (Scopus). Therefore, it must be noted that we are in the process of continuously updating the publishing procedures in order to improve the journal and bring it to a higher scientific status. Furthermore, our future aim to contribute effectively to the Arab publishing and scientific research movement in order to enhance the status of the scientific research and expand its horizons in Arab countries because we believe that the scientific research is one of the factors in the progress of the nations and is an indicator of its progress.

Prof. Dr. Fuaad Mohammed Freh
Editor in Chief

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- If the research involves a questionnaire or other data collection tools, a complete copy must be provided unless it is already included within the manuscript or appendices.
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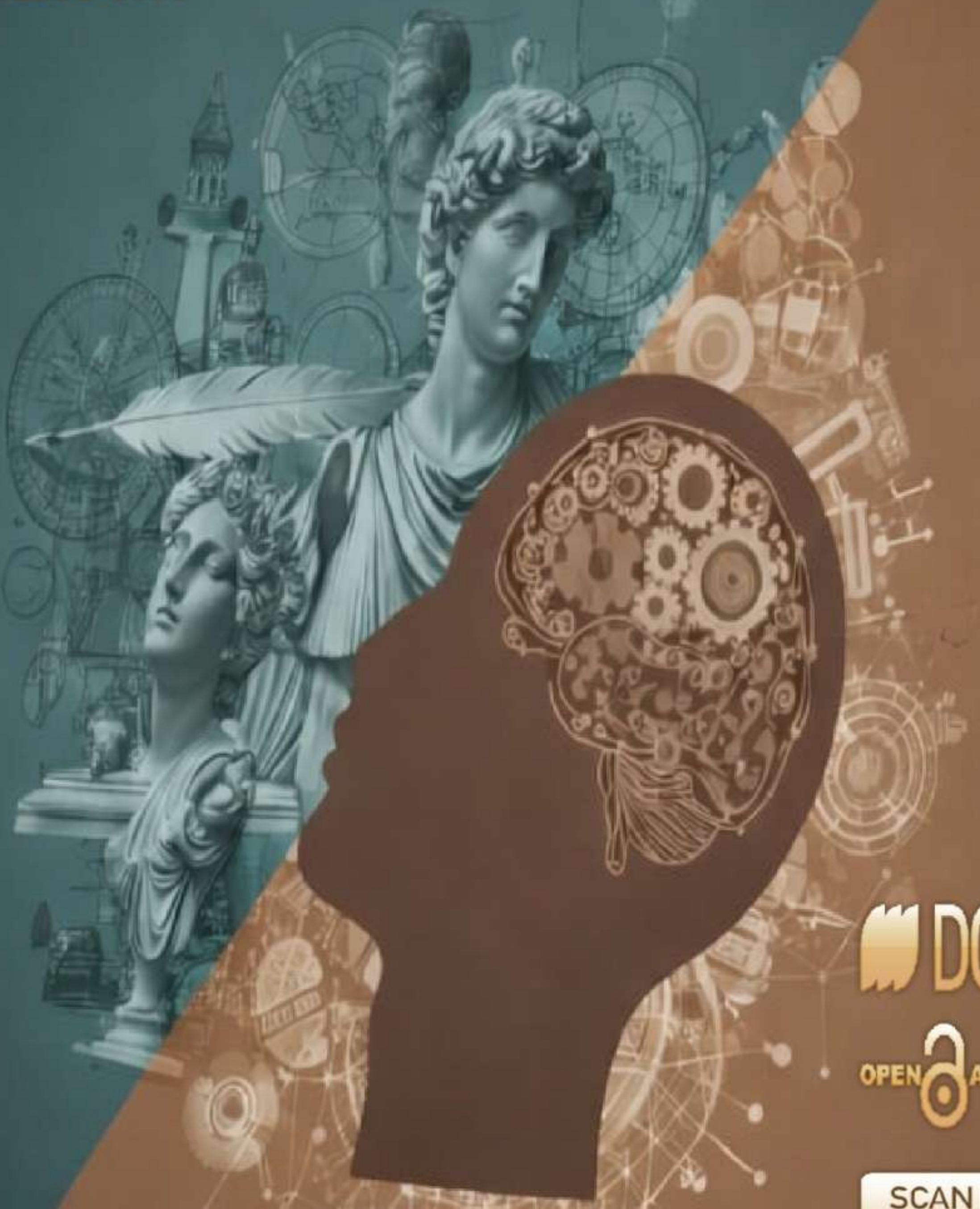

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