Urban Landscape Fragmentation as an Indicator of Urban Expansion Using Sentinel-2 Imageries

Nada Kadhim [1] , Nabil T. Ismael [2*] , Nabil M. Kadhim [2]

[1] Department of Civil Engineering, Faculty of Engineering, University of Diyala, Baqubah, Diyala 32001, Iraq.

[2] Department of Architecture, Faculty of Engineering, University of Diyala, Baqubah, Diyala 32001, Iraq.

Abstract

Rapid urbanization in some cities has led to the emergence of numerous subsidiary settlements around their primary cities. Due to this rapid urbanization and growth, there is a great demand for urban land, mostly for commercial, industrial, and residential uses. Urban green spaces and vegetation are at risk due to a large amount of urban land, as seen by a decline in connectivity and increased fragmentation, especially due to land conversion. However, the identification of the spatial and momentary variability in the clustering and fragmentation of vegetation patterns in urban settings has not made full use of local indicators of spatial distribution measurements, such as Baqubah, a city in Iraq. Since it is essential to measure the degree of fragmentation and evaluate urban expansion trajectories consistently, this study proposes a new approach to assessing the anticipated direction of urban extension, using the fragmentation indicator of built-up patterns in urban areas. Sentinel-2 data was used to map the fragmented urban centres and their future extent in the city at a single time point. The proposed method employs indices to capture the initial distribution of spatial patterns of vegetation cover and built-up areas. The main extracted land cover classes, landscape fragmentation performance, and surface density analysis were accomplished in ArcGIS. The results indicate that the entire built-up area in Baqubah has a high degree of fragmentation at 75%, and about 23% of the open space within the urban extent of the city. Two predicted trajectories of urban expansion were also revealed: one may follow the external road direction, while the other is multi-directional, commencing from the edges of the built-up area. The study concludes that the new method is useful for comprehending and assessing urban landscape fragmentation, as well as anticipating its path. This integrated approach to remote sensing and GIS can sufficiently and effectively determine priority urban regions for successful planning and management. In addition, our study's findings highlight the potential of the suggested strategy as a useful spatially explicit method for determining the spatial clustering and fragmentation of urban landscape patterns.

Keywords: Remote Sensing; GIS; Built-up Area; Urban Open Space; Expansion Trajectories; Surface Density; Indices.

1. Introduction

Cities play the most influential role in global issues such as global warming and sustainability [1]. As large settlements of humans, they typically form the center of urban areas from which interactions emerge between human activities and natural resources. These areas are becoming increasingly urban due to high population growth, various socioeconomic actions and exertions. Rapid urbanization, moreover, threatens open and green spaces and vegetation cover in urban areas, as evidenced by a decline in connectivity and higher fragmentation levels [2]. The urban expansion of a city starts, therefore, with the establishment of a new core in a built-up area, representing a form of urban landscape fragmentation. Such fragmentation is evident in the appearance of spatial discontinuities in the urban structure, seen in

small, detached patches of built-up area, usually occurring both inside and outside a city's fringes [3]. In this vein, landscape fragmentation is defined as the disintegration of large areas of natural land into small segments rather than isolated patches, regardless of the total area of natural land [4]. The consequences of landscape fragmentation may be an increase in the number of patches, a reduction in patch size, a rise in patch isolation, and the loss of many species and habitats [5]. Natural landscape fragmentation has also been related to biodiversity loss and changes in ecological function during urbanization processes [6]. Fragmentation can also have a significant impact on ecosystem services, human societies, and city dwellers' well-being [7]. Nevertheless, urban landscape fragmentation is a more important factor in the sustainable development of thriving urban and rural areas than urban growth [8].

The considerable body of published literature on the fragmentation of landscapes can be differentiated by findings, which are dependent on various aspects of landscape fragmentation. For instance, researchers have attempted to identify and evaluate the key factors which may cause this type of fragmentation, such as: unplanned urbanization and urban sprawl [9, 10], recreational human activities [11], land use changes [12], rapid socioeconomic development [13, 14], and discontinuous developmental trends [3, 15]. Other researchers have studied the impacts and consequences of urban landscape fragmentation. With this intention, one major issue in early urban landscape fragmentation research is the appearance of discontinuous patches in urban areas. Such isolated urban patches are an effect of the fragmentation process, representing the development of peripheral growth centers around the old core of a city [16]. The fragmentation of urban landscapes can also be evidence of either strong or negligible effects on urban environments, such as the marginal effect of urban fragmentation, on all spatial scales, on air quality [17, 18]. Conversely, however, increased urban landscape fragmentation results in the diminishing of urban green spaces [18]. The fragmentation of urban areas may also have a negative effect on transportation, the urban environment, and eventually the distribution of urban characteristics and functions [19]. In contrast, the low fragmentation of urban functional districts (industrial and mixed-use lands) has a negative impact on $CO2$ emissions, whereas less fragmented residential and municipal lands have a positive impact on $CO2$ emissions [20, 21].

Evidence suggests that urban landscape fragmentation is a tangible, spatial process of change whose formation can be observed in rapid population rises over time. Additionally, due to their isolation and diverse patch sizes, which may be caused by strong human influences of urbanization, the heterogeneous clusters of vegetation patches have a high possibility of being at risk from a conservation perspective [22]. Isolated and undersized fragments can arise in and around their original cities to meet the demand for dwellings and infrastructure [23]. Hence, the fragmentation process strongly indicates how human activities are energetically and continuously increasing the exploitation of the land [24]. Low urban land use efficiency, in particular, is what encourages informal settlements, urban sprawl, and fragmentation [25]. Latest analysis suggests that there are substantial nightly thermal gradients between urban and rural areas [26]. Based on the use of numerous indicators, rising land surface temperature (LST) and urban heat island (UHI) intensities have shown a positive link with impervious surfaces and a negative correlation with green surfaces [27]. In this sense, land transformation is a result of human activities and can be assessed by evaluating the fragmentation of the landscape. If we can grasp the spatial pattern of urban landscape fragmentation, this will improve our understanding of newly-formed urban centers and their development trajectories. The assessment of land fragmentation has thus become urgent in terms of how it provides information which allows us to determine the location of isolated urban patches.

However, in the case study city of Baqubah, Iraq, these spatially evident processes of landscape fragmentation have received little attention in the literature compared to the extensive studies conducted on many global cities. Although Baqubah has recently experienced the urbanization of much of its vegetation land cover, no previous study has investigated the landscape fragmentation of the city based on modern geo-databases, such as remote sensing data. Capturing the growth of cities from space enables us to estimate the extent of urbanization and its trends in those cities. As an indicator in the spatial analysis of urban areas, the assessment of urban landscape fragmentation using satellite imageries can reveal many isolated urban patches; this is because the fragmented urban area indicates human activities and provides evidence of the urban expansion process [24, 28]. One possible reason for the lack of studies in our target area is the use of traditional non-cost-effective methods of gathering and analyzing urban expansion information. For instance, statistical methods that depend on field surveys are time-consuming and require greater effort, and so such traditional approaches cannot keep pace with a city's rapid changes.

Instead, landscape patterns can now be assessed at various temporal and spatial scales due to the availability of remote sensing data [1]. More convenient indices and methods can also make findings easier to interpret and likely to generate concrete inferences [24]. Although some research has been conducted on detecting landscape fragmentation patterns at different times in captured satellites images [2, 8, 14, 23], there is still very little scientific understanding of the discovery of a landscape fragmentation pattern for a single time interval of interest. In particular, this relates to the trajectories and trends of a city's urban expansion, as well as how we may derive these from the patterns of urban landscape fragmentation for a specific year. In this regard, a solid basis for the explicit spatial mapping of landscape fragmentation at the pixel level is urgently required for Baqubah, to facilitate the depiction of internal and external fragmentation of the urban area. For this reason, the investigation and identification of the level of fragmentation of the land in the city is required. Accordingly, the mechanism by which urban landscape becomes too spatially fragmented to construct parcels with single or mixed land use is known as land fragmentation [8]. This significant land-use change has the potential to affect natural ecosystems and habitats, as well as the quality of life in cities [24].

In this context, the urban integrity and open spaces in Baqubah are threatened by the fragmentation of construction land that has appeared due to decentralized urban growth, chaotic mixed land uses, and sizeable infrastructure required for transportation. This indicates a need to understand the degree of fragmentation that exists in the city at a certain point in time. Quantifying the fragmentation of the urban landscape in a consistent manner, based on appropriate indices and analysis, can provide useful indicative information for inclusion in strategy formulation decisions. Therefore, our research contributions in this study consist of the three objectives we seek to achieve: (1) identify the distribution of the vegetation and built-up regions within the study area by employing well-defined spatial indices, then determine the main classes of land cover by using a classifier applied to the selected satellite data to accurately localize the classes and obtain a realistic analysis; (2) derive the four key categories of the city's landscape fragmentation to assess the degree of urban fragmentation and determine the total percentage of openness inside and outside the built-up areas at the time captured in the satellite data; (3) estimate the future trajectories of the urban expansion which may occur in the city by developing an integrated analysis method that exploits the former outcomes of data processing, and considering the urban fragmentation as an indicator of the anticipated expansion of human settlements. These goals will be the cornerstone of future research investigations into the city and will open the way for appropriate decision-making to improve life for the residents and preserve the natural resources of the city. After this section, the article is organized in the following manner: Section 2 gives a description of the study area. In Section 3, the used data and the methodology are presented. The outcomes and discussions of this study are presented in Section 4. The conclusions are finally explained in Section 5.

2. Case Study Area: Baqubah

Baqubah is a city within the belt of Baghdad, the capital of Iraq. As the capital of Diyala Governorate, Baqubah is situated in the west and positioned around 60 km northeast of Baghdad (longitude 44° 38' 37.18" E, latitude 33° 44' 47.72" N). There are no reliable estimates of the population of Baqubah, but the city presently has an estimated population of about 152,550 capita[*]. The administrative boundaries of the city considered in this work cover an assessed area of 307.64 km^2 Figure 1. The city is fertile because it is geographically located on a low plain, and has access to the Diyala River and other small streams. Its large open spaces have been exploited for urban growth, and land has transformed from agricultural to residential, industrial and commercial uses. At the moment, the increase in the fragmentation of the built-up areas is particularly noticeable in Baqubah due to urban growth and other factors, such as security instability, demographic change, and socioeconomic factors. The unplanned expansion of the city has led to the fragmentation of the city into urban patches, and this activity has focused attention from planners and decision-makers on the continuous attrition of open spaces and agricultural lands. Nevertheless, we found no studies assessing the fragmentation of Baqubah landscapes, and for this reason, Baqubah was chosen for this study because it is in a persistent state of transition caused by the rapid urban growth and landscapes fragmentation changes characteristic of most urban areas in Diyala.
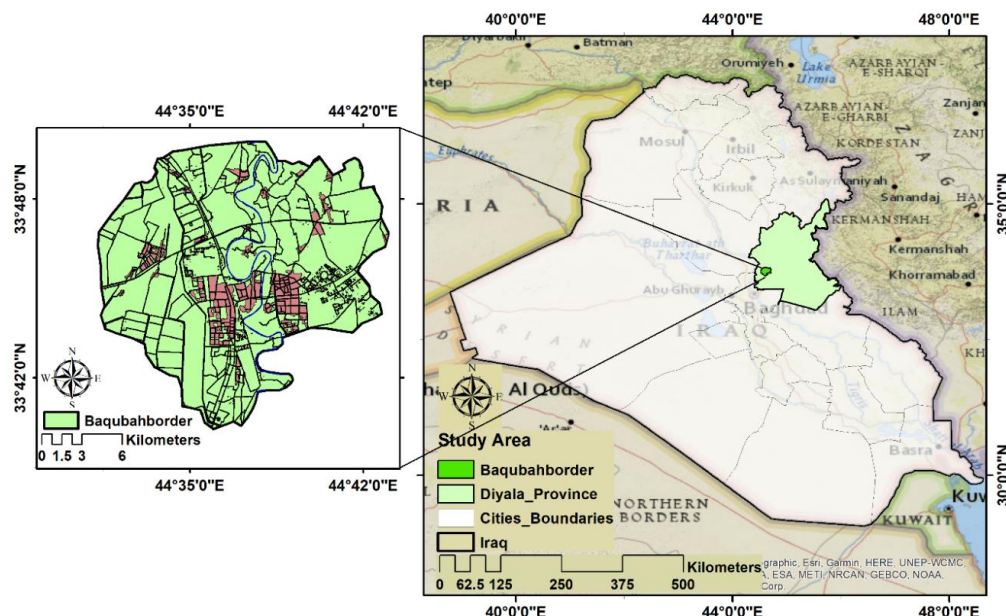

Figure 1. The location of Baqubah (National Geographic World Map)[†]

---

[*] Source: © 2020 World Population Review, https://worldpopulationreview.com/countries/cities/iraq

[†] The images were downloaded from the Earth Observation Programme of the European Union, organised and operated by the European Commission in cooperation with the European Space Agency (https://scihub.copernicus.eu/dhus/#/home).

3. Data and Methods

This study offers a novel technique for assessing urban expansion using multispectral Sentinel-2 images, using the fragmentation of the urban landscape as an indicator, as shown in Figure 2. Our approach is founded on the knowledge that the transformation of the land's cover into urban areas can be observed using optical satellite images [1]. The methodology starts with: (1) a preliminary evaluation of the study area by applying two commonly used spatial indicators on satellite images (subsection 3.2); (2) after selecting many different types of land cover samples, a machine learning classification process was applied to the images to generate the only three main interesting classes which can meet the purpose of the study (subsection 3.3); (3) the landscape fragmentation tool was applied to the two reclassified land cover classes to provide an indication about how the study area is fragmented (subsection 3.4); (4) finally, we propose an original approach for estimating the location and direction of urban expansions using based on a spatial analyst strategy (subsection 3.5).
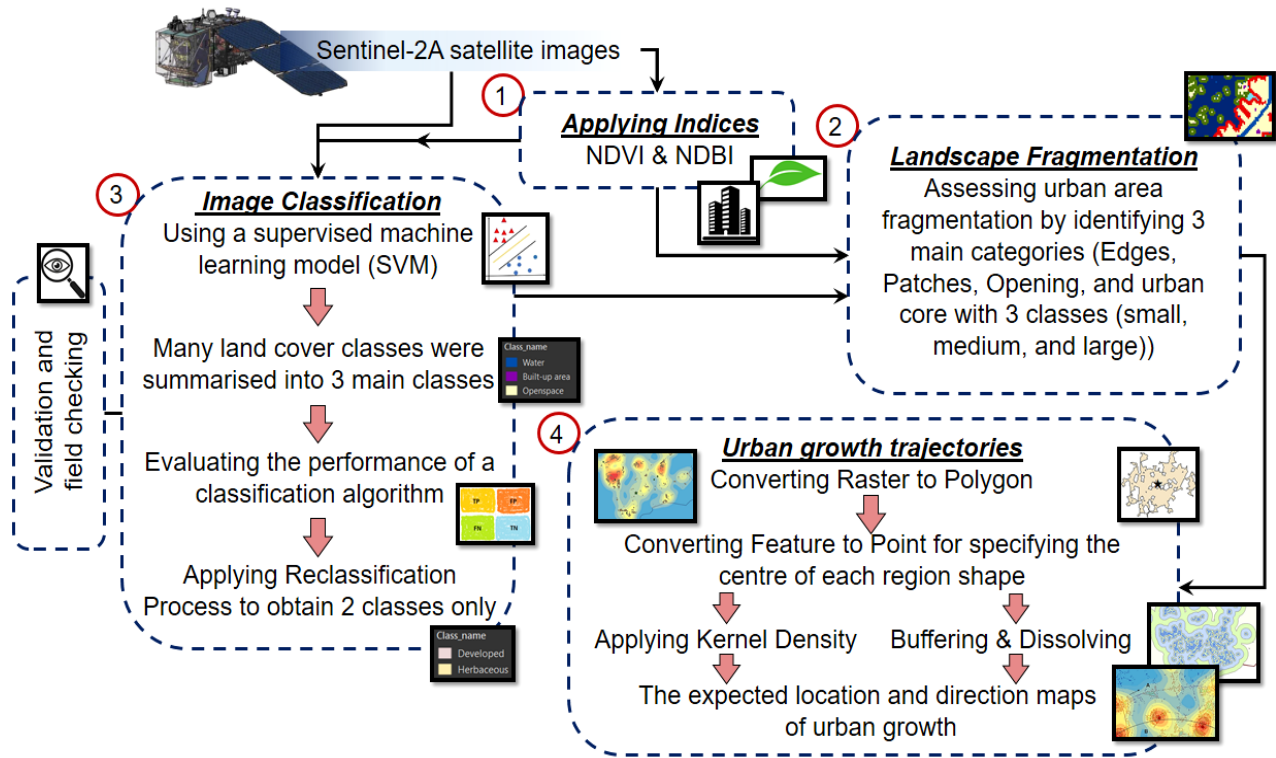

Figure 2. The proposed method for the assessment of urban landscape fragmentation

3.1. Multi-spectral Satellite Data

In this study, free and downloadable* Sentinel-2 satellite images were used, as shown in Figure 3. Thirteen spectral bands are captured by Sentinel-2's multispectral sensor: four 10m bands, six 20m bands, and three 60m spatial resolution bands. Because the six bands at the resolution of 20m fulfil the criteria for improved land-cover classification and geophysical parameter retrieval, this moderate resolution was chosen for this study. In particular, the 20m image bands from the Sentinel-2A satellite include four bands (5, 6, 7 red edge and 8 narrow near-infrared) as well as two SWIR bands (11 and 12 shortwave infrared bands).

The latter supports inclusive land-cover, land-use and detection maps of change, and also provide key details about the condition of the vegetation. The level-2A orthorectified and atmospherically corrected images cover more than 100×100 km^2 of the observed Earth's surface and their tiles are typically in UTM/WGS84 projection. The selected Sentinel-2A data are also cloud-free scenes, meaning there is no need to conduct further improvements on the image. Baqubah is fully covered by Sentinel-2A images due to the ability of the multispectral satellite sensor to provide geospatial data at local, regional, national and international scales. Because this study was the first of its kind on this location, and on the cities of Iraq more generally, the data were selected based on the most recent date. Accordingly, the six 20m image bands of the multispectral Sentinel-2 were acquired by Sentinel-2A on 20 July, 2020, at 07:46:19.

---

* Service layer credits: - National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.
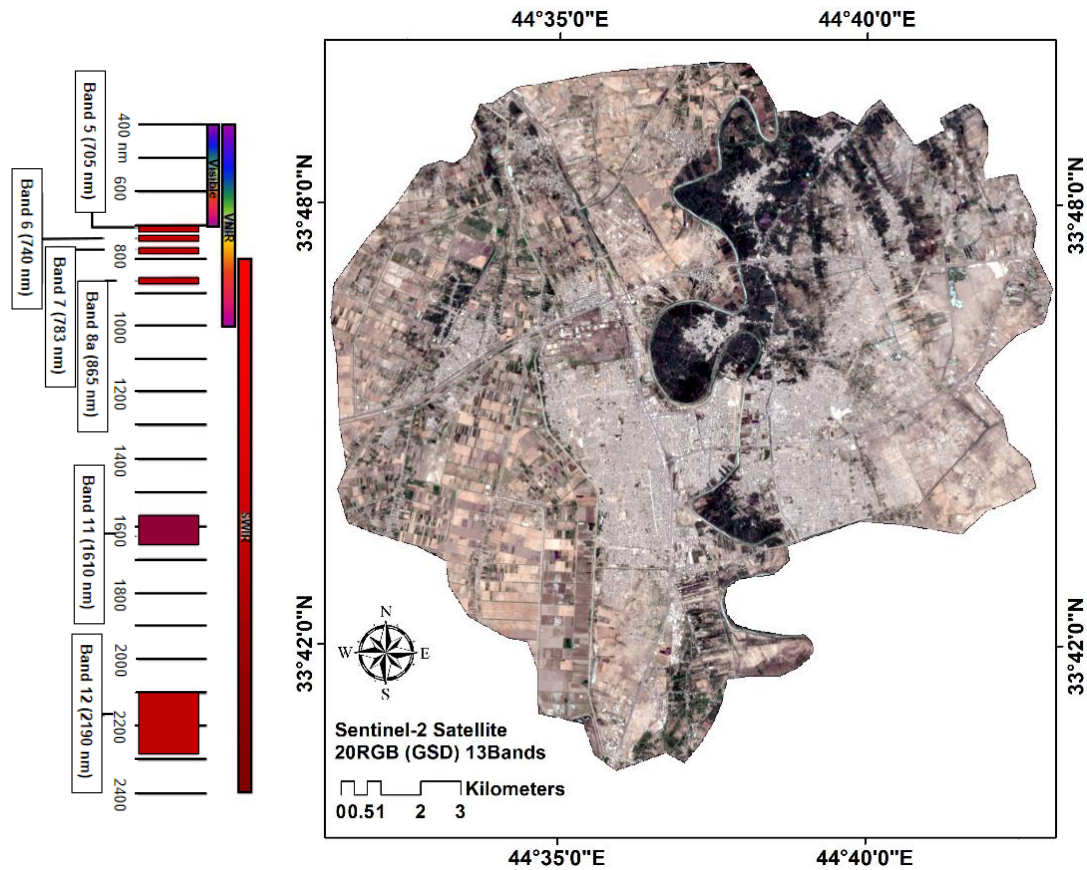
Figure 3. Sentinel-2A satellite imagery of the study area with the multispectral scale of six bands having a spatial resolution of 20m GSD, from a total of thirteen bands

3.2. Primary Evaluation of Urban Area

A rough estimate of green and open spaces can provide a first impression of their size. To derive the extension of the built-up and vegetation regions in Baqubah, two spatial indices were utilized. Non-vegetated and vegetated areas were recognized using the well-known and widely employ normalized difference vegetation index (NDVI). The NDVI index relies on two key bands of satellite imagery: the red band (R) and the near-infrared band (NIR). In our case, vegetation red edge (Band 5) and NIR (Band 8) Sentinel-2A images were employed to extract the green areas in the city, via the following equation:

$$NDVI = \frac{NIR(Band08) - Vegetation\ RedEdge(Band05)}{NIR(Band08) + Vegetation\ RedEdge(Band05)} \tag{1}$$

Although the index is simple, it is efficient as a green vegetation quantification index. It normalizes the dispersion of green leaves at near infrared wavelengths through the absorption of chlorophyll at red wavelengths. The NDVI's value range is -1 to 1. The distinction between vegetation cover and the bare ground is further noticeable on consideration of the time captured by the Sentinel-2A satellite images (the dry, summer period of the year). Therefore, the division of areas of vegetation from patches of bare soil, very sparse cover, water, and urban areas can be clearly indicated, to facilitate the determination of urban landscape fragmentation. The second index used is the Normalized Difference Built-Up Index (NDBI), computed by employing the NIR (Band 8) and the SWIR (Band 11) from Sentinel-2A, as follow:

$$NDBI = \frac{SWIR(Band11) - NIR(Band08)}{SWIR(Band11) + NIR(Band08)} \tag{2}$$

In the SWIR region, the NDBI index identifies urban regions with greater reflectance relative to the NIR region. The NDBI is used to determine the built-up characteristics and has indices between -1 and 1, in addition to its roles in land-use planning and watershed runoff forecasts, as primarily designed by Zha et al. [29]. The purpose of using the NDBI was initially to differentiate between built-up and non-built-up areas by processing the Sentinel-2A images to primitively specify the urban patches. Hence, to fulfil the investigation of the spatial pattern of the city, the two aforementioned spatial indicators were computed. We discriminated between two processing outcomes by using different map color systems for both indices so that the NDVI map is shown on the right side of the final results and the NDBI map is shown on the left in the results and discussion section.

3.3. The Supervised Sentinel-2A Image Classification Method

The supervised classification approach was used to classify the Sentinel-2 image with 20m GSD and extract the main categories of the city's land cover. The multispectral bands of the satellite image can be utilized to distinguish water bodies and impermeable surfaces that essentially refer to built-up areas. This allows land cover regions to be classified with a high degree of accuracy by advanced algorithms into the three groups of water, open space, and built-up region as shown in Table 1. The purpose of determining these three land cover classes was to disclose the fragmentation pattern of the city's urban landscape. For training, sample sites were drawn on the image as polygons and allocated to a specific land cover class of built-up, open space (non-built-up), and water. Thereafter, a Support Vector Machine (SVM) classifier algorithm in ArcGIS Pro 2.5 was used to classify the image depending on the locations of the chosen training samples. The SVM classifier requires only a few samples as it is well adapted for segmented raster data and the handling of standard imagery, due to its ability to deal with multiband imagery of any depth.

Table 1. Classification of the multispectral bands of the satellite image of the study area

No.	Land cover classes	Red band	Green band	Blue band	Classified Pixels
1	Water	84	117	168	11544
2	Built-up area	232	209	209	102751
3	Open space area	253	233	170	415345

To confirm the classification results of the land cover using an objective collection of ground verification points, an independent accuracy assessment of the Sentinel-2 classified image was performed. Validation datasets for the image classification were attained from the three sources. Firstly, we randomly selected points within each land cover class and cross-referenced to Google Earth imagery and very high resolution (VHR) satellite images provided by the municipality of the city; thus, the classification accuracy assessment was obtained. Second, to substantiate the site of the random points from the Google Earth and VHR satellite imageries, further verified information from field surveys was obtained. The locations of the ground truth points were randomly collected during the fieldwork surveys, including the point coordinates captured by GPS, its site description, and its land cover class. Recently, because of their high geometric accuracy and delicate spatial resolution, the VHR satellite imageries of Google Earth have become prevalent as a data source for land cover classification validation [30, 2].

By dividing the total summation of the number of correctly classified values over the total number of values, the overall accuracy was calculated. The distribution of the correctly classified values was across the confusion matrix's upper-left to lower-right diagonal. The total number of values in either the truth or the predicted-value arrays represent the number of values in Table 2. To measure the overall and categorical accuracy, the Kappa coefficient was determined. The agreement between classification and truth values was evaluated by a Kappa value, such that a kappa value of 1 stands for perfect agreement, while a value of 0 does not stand for agreement, Table 2. The land cover map extracted from the image classification was later reclassified for further examination into developed and undeveloped areas.

Table 2. Overall accuracy and the kappa coefficient of the image classification

Land cover classes	User accuracy (%)	Producer accuracy (%)
Water	0.64	1
Built-up area	1	0.85
Open space area	0.97	0.82
Overall Accuracy	0.87%	
Kappa coefficient	0.80%	

3.4. Assessing Urban Landscape Fragmentation

Based on the output of the land cover classification and the indices of the built-up and vegetation regions, our approach is proposed for the measurement, quantification and mapping of the urban landscape fragmentation pertaining to a particular snapshot in time. Because the interest of our current research is to assess the fragmented urban areas within Baqubah, the analysis was developed for built-up land covers and the effect of urban neighborhood segmentation on open spaces. Vogt's algorithm for segmenting the satellite image's pixels [31], presented as a landscape fragmentation tool version 2 (LFT v2.0) by the Centre for Land Use Education and Research (CLEAR) at the University of Connecticut, was adopted to investigate the urban land fragmentation in the city. While originally intended for the study of forest fragmentation, LFT v2.0 is also applicable to any form of interest relating to land cover [32]. The LFT tool is operable in the GIS environment in an integrated manner, and so LFT v2.0 was applied to the classified image by adding it to ESRI© ArcMap 10.4.1 to obtain further understanding of the fragmented urban land cover. However,

because the landscape fragmentation algorithm was limited to the correct order of the two classes only, the classified image with three classes (water, built-up and open space) was reclassified, reordered and renamed into the two classes of urban (developed land) and non-urban (undeveloped land) as an input binary image. Therefore, the input classes of classified land cover contain: 1=non-urban and 2=urban regions. The class of water land cover was assigned a no data value and thus the fragmentation evaluation is unaffected by no data pixel values.

Three main classes and three sub-classes were created as a result of the assessment procedure for urban landscape fragmentation. These categories include the opening area (an inner aperture within the core area), the patch area (small segregated pieces of the urban area), and the edge of the core regions. The core of the built-up area is comprised of built-up pixels in locations with high spatial densities (built-up pixels along the exterior perimeter of the urban area). Small, moderate, and large are the three sizes of the core region, depending on the values assigned to urbanness. The pixels in the built-up and open space zones were discriminated against using two metrics by establishing these groups. These two indices of urban fragmentation are crucial to the study of cities since they are highly connected [33]. The first measure can provide an indication of the fragmentation saturation computed in the following equation:

$$Fragmentation\ saturation = \frac{Built-up\ Area}{Urban\ Extent} \tag{3}$$

The areas of the built-up space and urban extension were first extracted from the NDBI index and the image classification. The second measure is the openness index, which represents any built-up pixel within the urban extension has an average share of open space pixels within the walking distance circle (a circle with an area of 1 km^2) [33], as follows:

$$Openness\ Index = \frac{Urbanised\ open\ space}{Urban\ Extent} \tag{4}$$

The outcomes of the NDVI index and the image classification were used to identify both the urbanized open space and urban extent values in Equation 4 above. The values of both indices varied from 0 to 1. Saturation was highest where there was no open space at all in the urban area and lowest where there was just open space. In contrast, the openness index was highest where the major city had only open space and lowest where there was no open space at all [33].

3.5. Determining the Rrajectories of Baqubah's Future Urban Expansion

In our new proposed approach, the trajectories of the expected urban growth of Baqubah were defined using the urban landscape fragmentation of the city as an indicator. To improve understanding of the distribution of emerging settlement gatherings (urban patches), a density surface calculation can illustrate the location of the city's higher and lower proportions of urban open space areas. Accordingly, we focused on those urban patches with an area of <250 acres in the new built-up core regions. Emerging urban patches and their adjacent open areas are the main motivators of continuous land development, leading to urban expansion. In this context, the Kernel density tool —part of the suite of spatial analyst tools in ArcGIS —was used to create a density surface map of the future urban expansion in Baqubah. Because we had obtained an important indication of the fragmented landscape of the urban area in the city using our proposed approach, we took advantage of the information we had extracted on urban patches and open space areas. The patch class was converted from raster to vector form so that the spatial analysis could be conducted. The center of each polygon shape, which represents a patch in the built-up area, was identified to provide an indicator how these patches are adjacent and the orientation of their density. Additionally, to attain an estimated prediction of the direction of lands that might be developed in the future, 100 m, 500 m and 1 km dissolved circle buffers were constructed around open space areas relating to the built-up patches. This facilitates the identification of the availability of open spaces inside and outside the patches. Thereafter, the kernel density tool was used to compute the density of the patches centers (points) in the vicinity of these points. In theory, each point is covered by a smooth curved surface, the maximum value of which is at the point, decreasing as distance from the point increases, and eventually reaching zero at the search radius distance from the point in Figure 4. For every new (x, y) location for points, we calculated the predicted density by identifying the default search radius using the kernel density formula:

$$Density = \frac{1}{(radius)^2} \sum_{i=1}^{n} \left[\frac{3}{\pi} \cdot pop_i \left(1 - \left(\frac{dist_i}{radius} \right)^2 \right)^2 \right] For\ dist_i < radius \tag{5}$$

where, input points represented by $i = 1, \dots, n$. Only points within the radius distance of the (x, y) position are included in the sum. pop_i is the value of point i's population area, which is an optional parameter. The distance between any point i and the locations of the centers (x, y). The density is then multiplied by the number of points measured[*]. The map of urban expansion prediction illustrates the potential of the centers of urban growth in the city. Through their surface density, these centers can potentially determine the orientation of urbanization based on urban open space density concentration within and around the built-up areas. This use of the spatial indication of city fragmentation can thus help identify the likely axes of urban extension.

---

[*] Esri resources: Tool Reference, Geoprocessing Tools, Spatial Analyst toolbox, Density toolset, Density toolset concepts.
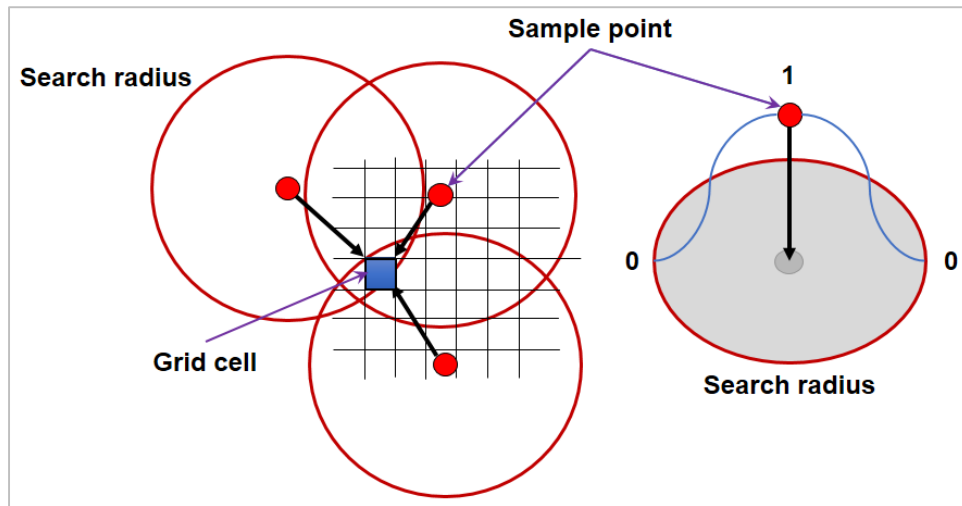
Figure 4. Kernel density, showing how to calculate the distance between a cell and an input

4. Results and Discussion

Urban landscape fragmentation, as an indicator derived from sets of analysis indices and classification processes, can determine the spatial fragmented patterns of a city, in this case Baqubah, Iraq. With respect to the first research objective, we found that the proportions of vegetation cover and built-up regions in Baqubah in 2020 were 21% and 18%, respectively, relative to the total landscape of the city. Both areas were successfully mapped using Sentinel-2 medium spatial resolution imagery by applying NDBI and NDVI indices, as shown in Figure 5. Although the amount of developed land was only 3% greater than the vegetation cover, this accounted for 40% of the entire exploited lands area of Baqubah, as a type of land use, Figure 6. As we can observe, the calculated indicators facilitated the identification of the initial spatial patterns of both urban footprints and vegetation regions, indicating their actual locations within Baqubah. However, the indices are a binary result and so it is difficult to recognize multiple classes of city land cover at the object level. The SVM classifier was therefore applied to the multispectral Sentinel-2 image to determine the main classes of land cover to accurately localize the classes and then obtain a realistic analysis of the urban fragmentation, as shown in Figure 7. The findings of the image classification are presented in Figure 8, which illustrates three main land cover classes, focusing on the built-up area in order to assess the urban landscape fragmentation in the city. Although the confusion matrix of the classification results shows some false negative and positive values for pixels that should have belonged to the water class, the overall accuracy was 87% and the kappa coefficient value of land cover classification was determined as 80%, depending on ground truth values in Table 3.
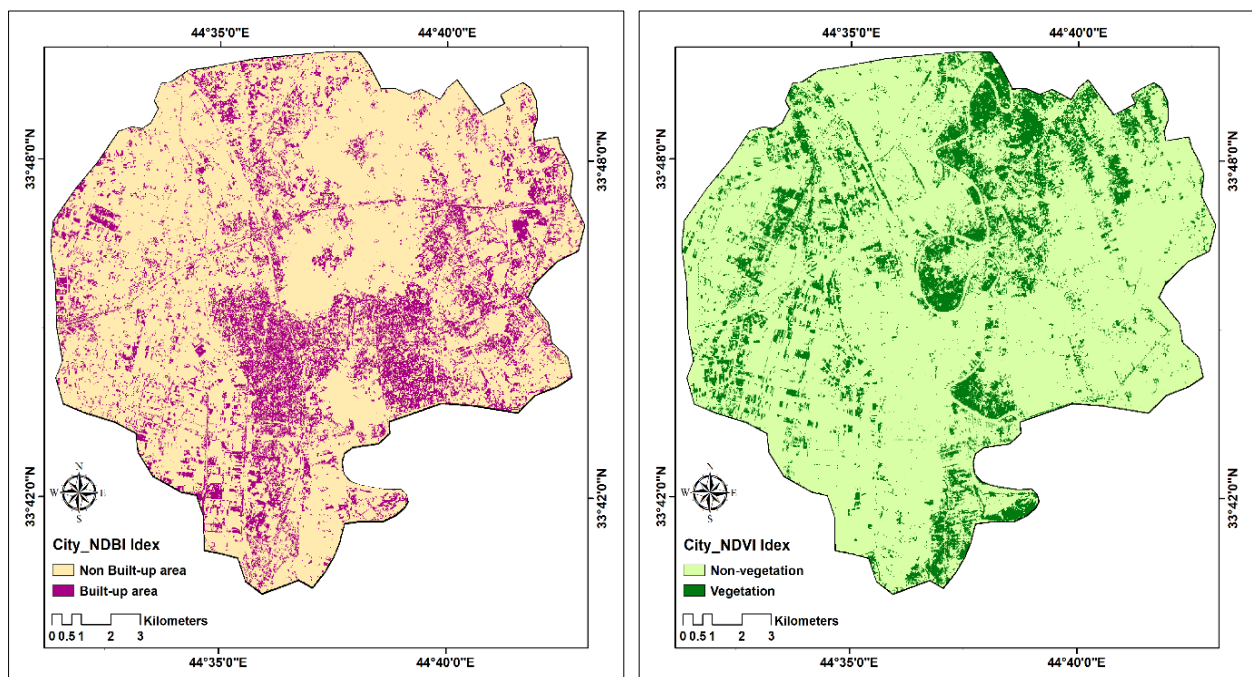

Figure 5. NDBI index of Baqubah (left), and the NDVI index (right)
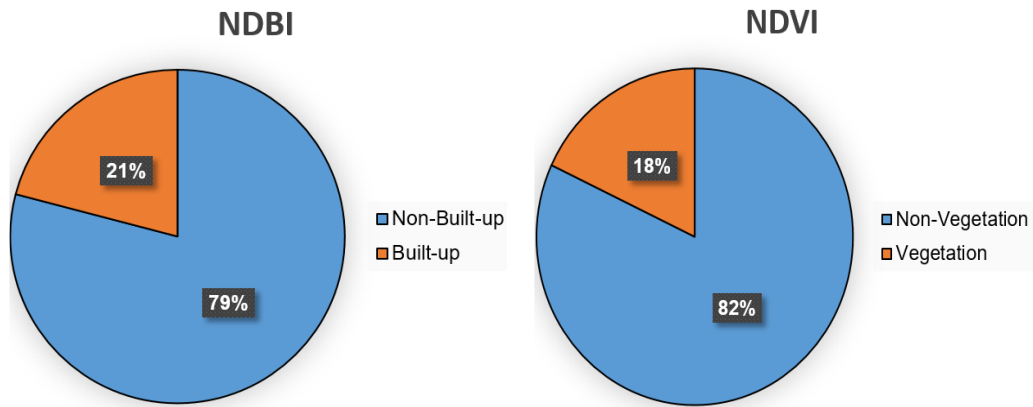
NDBI

NDVI

Figure 6. Percentage of vegetation and built-up land cover of the city landscape using NDVI and NDBI indices, excluding water cover
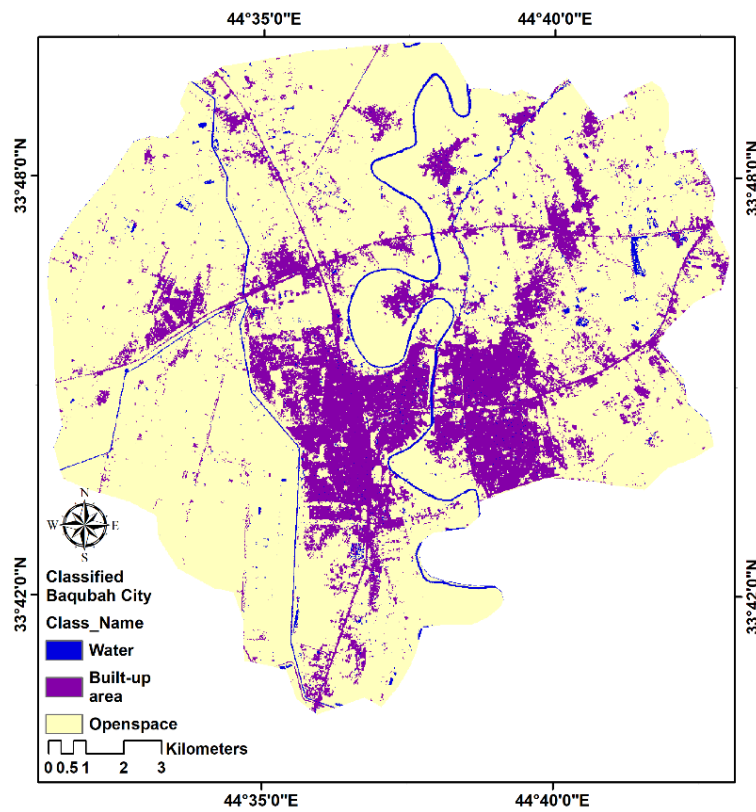

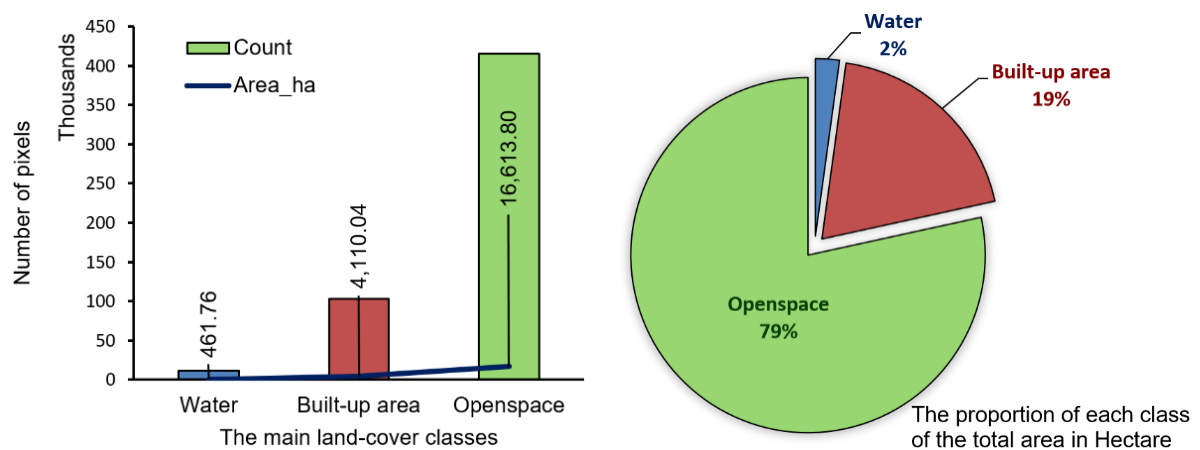**Figure 7. Land cover map of Baqubah, Diyala, Iraq, in 2020**

Figure 8. The three classified land cover classes and the percentage of their total area of the city after image classification

Table 3. Direction of urban growth in Baqubah after applying kernel density. Direction A is along the international external road of the city and B is the orientation of the city's expansion from the former built-up cores

Fragmentation pattern	Pixel count	Area (ha)	Area (%)
Patch	16775	671	16.31
Edge	31501	1260.04	30.63
Opening (Perforated)	21131	845.24	20.55
Core (< 250 acres)	8878	355.12	8.63
Core (250-500 acres)	4788	191.52	4.66
Core (> 500 acres)	19754	790.16	19.22
Σ	102827	4113.08	100

Six classes were derived from the assessment process of urban landscape fragmentation, including three main classes and three sub-classes, Figures 9 and 10. These classes are the core of the built-up area (built-up pixels in areas with high spatial density), the opening area (an interior aperture within the core area), the patch area (small segregated fragments of the urban area), and the edge of the core regions (built-up pixels along the exterior perimeter of the urban area). The core area has the three levels of area size —small, moderate and large —depending on the determined urbanness values.
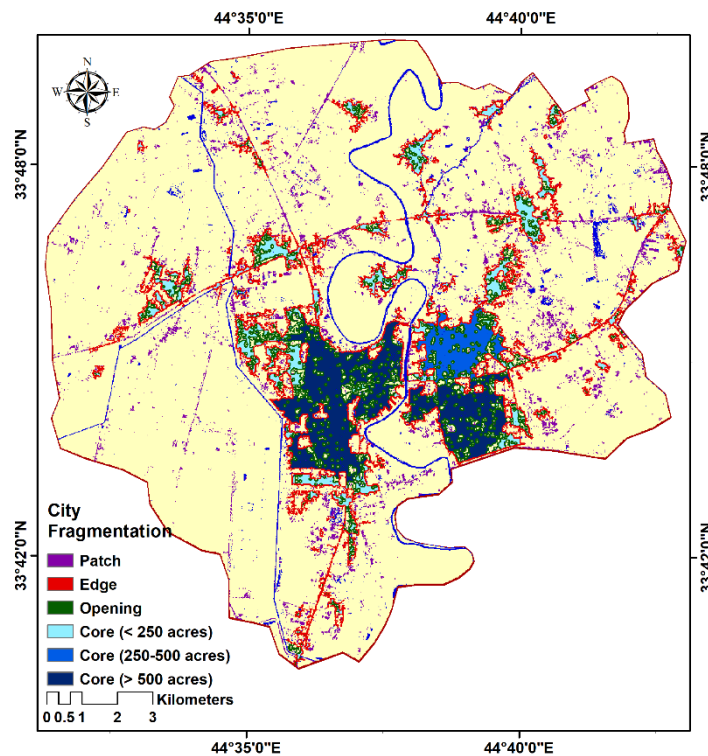

Figure 9. Urban landscape fragmentation map of Baqubah, with the four main classes
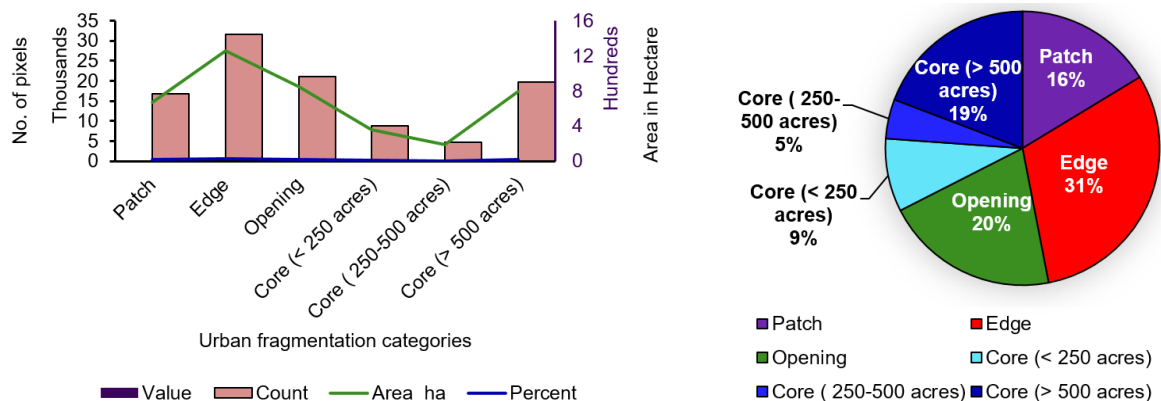

Figure 10. Built-up region, fringe open space, and captured land patches comprising the urban footprint in Baqubah. The same colour scheme was used in both spatial pattern map and statistical analysis of the urban landscape fragmentation

The results of the urban landscape fragmentation assessment for the key categories showed an unequal distribution and varying levels of fragmentation in Baqubah's built-up area, Table 3. The study found that the value of the urban landscape fragmentation for the entire built-up region in Baqubah in 2020 is 0.75, a finding which was expected due to the remarkable change and development in the land and the spatial pattern of the spread of urban patches in reality, as shown in Figure 9. The high value of urban landscape fragmentation indicates an increase in built-up area fragmentation and decrease in open spaces in Baqubah. The most likely factor that caused this result is the large gap between urban patch locations in the city, and this could explain why the density of urban areas is often lower than the density of the centers of the built-up areas [33]. In this context, the city demonstrates how scattered growth in built-up areas, arising from the forced exploitation of open land, is meeting the settlement demands of the population growth in Baqubah. Another important finding is that the openness index of Baqubah is 0.23, meaning that the city also has small patches of urban open space areas, making these spaces a target for future development. Typically, the ongoing fill-up stage of built-up areas will entirely urbanize small surviving open space areas [34]. However, the value of the openness index in Baqubah was low due to the urban extent in the city having the maximum saturation value for urban landscape fragmentation [33]. It is known that infrastructure gradually dismembers open space, which then becomes isolated through the growth of built-up areas, and indeed this is exactly what is happening in Baqubah. Regarding the calculated value of the openness index, the average share of open space pixels was derived based on the walking distance circle of a built-up pixel inside the urban extent, as shown in Figure 11. The two values of the aforementioned indicators were computed after applying Equations 3 and 4. These findings corroborate the results of a great deal of the previous work linking urban landscape fragmentation with open space areas, showing that these two measurements have a strong relationship [2, 8, 14, 34].
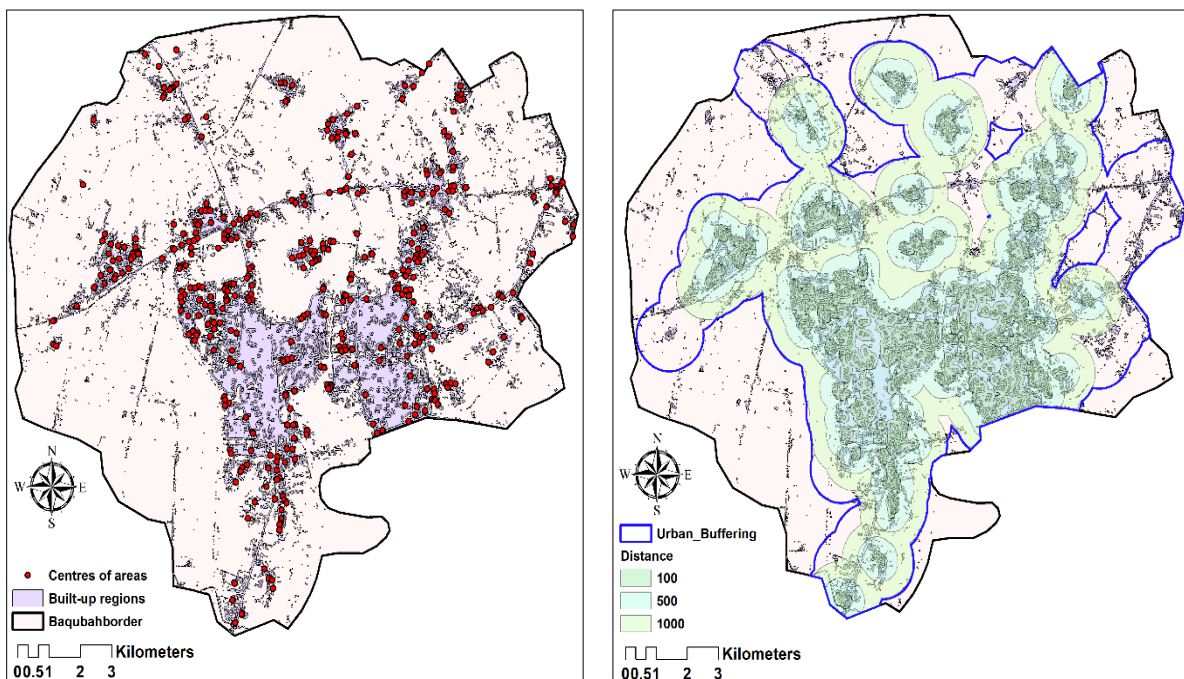

Figure 11. Spatial assessment map of the centres of urban regions <250 acres (left) and the creation of the buffer polygons around given open space areas to a specified distance (right)

Based on the classification outcomes, the urban fragmentation map adequately demonstrates the cores of built-up areas, edges, and patches, as well as urban open spaces, as the first objective of this study. In the built-up area, the urban footprint defines three degrees of spatial density. Built-up pixels in areas with lower spatial densities impact a larger region of open land than built-up pixels in high-density areas. The fringe open space, also known as the edge-disturbance zone, is land within 100 m of growth. In fact, isolation from other open areas degrades captured open land patches [31]. In Figure 10, there is a clear trend of an increasing perimeter of built-up areas in terms of the edge ratio of the urban area, which reached 31% compared to the other categories: 16% patches and 20% perforated areas (opening areas). From Figure 10, it can be seen that by far the greatest domain is for the urban edge, which represents, in turn, the same total percentage as the three-level urban regions' cores. The results of the fragmentation indicator allowed us to quantify and assess the urban area structure in terms of the spatial pattern distribution of both built-up areas and urban open spaces. The urban built-up area is depicted on the urban footprint map as follows: built-up pixels with urbanness values of >50%; for fringe open land, undeveloped pixels within 100 m of established pixels; and, for captured open land, areas of undeveloped pixels of <200 hectares fully surrounded by the urban and fringe open land pixels. With the abundance of unused land resources in most Baqubah lands, further urban development will inevitably be fragmented, which means

continually proliferating fragmented construction patches and increasing the density of construction across the entire built-up area. Moreover, owing to the patch size isolation of the built-up areas, which may be due to extreme human impacts of urbanization, the undeveloped lands have a high likelihood of being at risk, from a conservative viewpoint.

Regarding the third objective, our developed approach managed to estimate the axes of urban expansion in Baqubah. Based on the evaluation of newly developed land patch centers, the findings in Figure 11 suggest the range of the availability of urban open spaces in and around the centers of these patches through multiple dissolve buffers at 100, 500 and 1,000 m distances. The figure provides an indication of the spatial distribution of the modern fragmented urban patch clusters, which have an area of <100 hectares. However, this result does not indicate which areas are most eligible for urban expansion, nor their orientation. Therefore, after applying surface density analysis to calculate a magnitude per unit area from each point within a given region, as shown in Figure 12, we identified the central point of those developed patches most likely to become the points of origin for urbanization expansion into their surrounding regions.
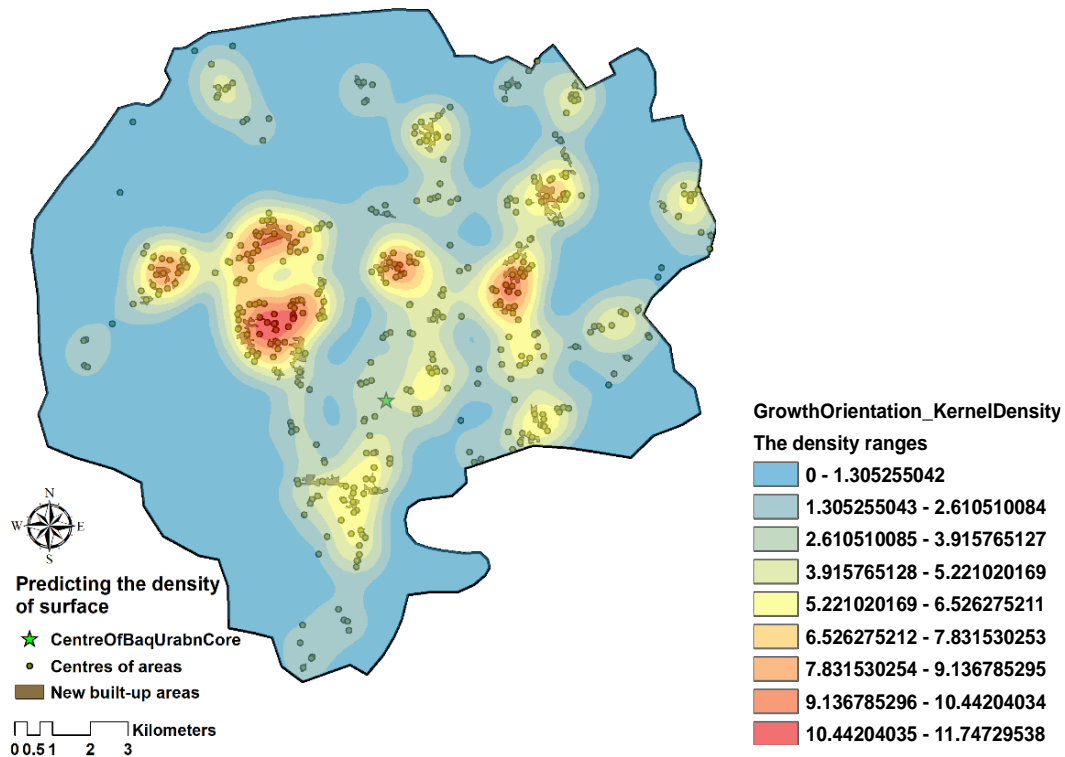

Figure 12. Expected spatial location and direction of urban growth by kernel density

The overlapping results in Figure 13 reveal the largest set of significant clusters of those developed lands expected to have an increase in urban expansion. This finding has important implications for assessing the trajectories of urban expansion in the city. In Figure 14, axes A and B indicate that there are two major potential paths for urbanization in the city, and that these may continue and extend in the near future. The estimated first direction of the urban expansion of axis A is along the international external road of the city. This is probably due to the fact that the three main positions of the surface density centers with the highest pixel value of 11 (red color), compared to the lower pixel value of approximately 1 (blue color), are located near this road. The values of the surface density centers refer to newly fragmented urban regions. Similarly, the three other main centers of surface density also have the highest values, as evidence of the strong possibility of their future growth. These regions established axis B's urban growth direction, in that the direction of the expansion is curved because it surrounds the former built-up area, due to the spatial distribution of the centers of areas with high surface density, Figure 14. This orientation of urban expansion proceeds from within the borders of the former built-up area to outside it, in the direction of the international road. A possible explanation for this result may be the existence of certain obstacles and limitations, such as orchards along the river, green spaces (e.g., parks, recreational areas and gardens), and state-owned property. The limitations represented by these land use types clearly influenced the shape of the second direction of predicted urban growth. Although our results also suggest there are many other potential directions for urban expansion in Baqubah, these are much less probable future pathways. Despite the results of the analysis generally revealing that other estimated trajectories will follow major city roads, this evaluation is limited by a lack of key information from the city municipality concerning which urban reserves might be protected from urbanization for 50 years after their designation. Furthermore, there is no accurate statistic for Baqubah's population growth to support our interpretation of spatially urban growth.
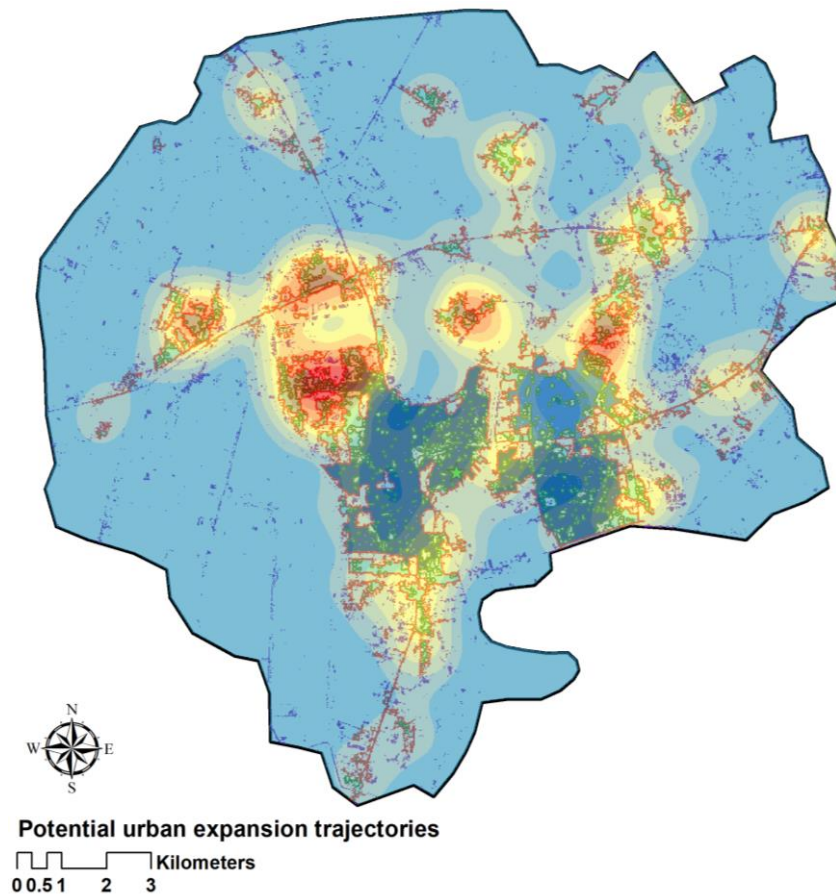
Figure 13. Centers and trajectories of future urban expansion in Baqubah
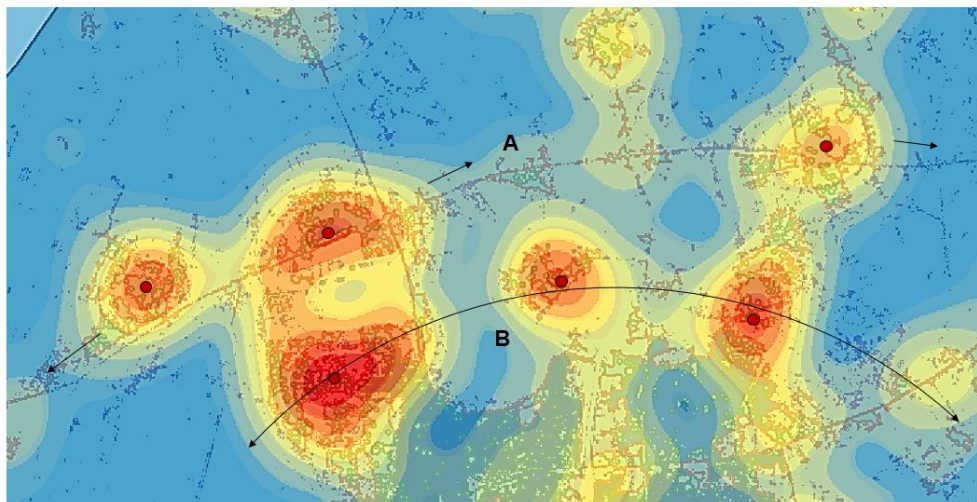

Figure 14. Direction of urban growth in Baqubah after applying kernel density. Direction A is along the international external road of the city and B is the orientation of the city's expansion from the former built-up cores

This analysis, based on remote sensing data, may provide a scientific framework for an effective understanding of fragmentation processes, as they can address the issue of high spatial variation and multi-scale heterogeneity in urban landscape fragmentation [2]. The approach used in this paper allows for accurate characterization of cluster analysis, spatial heterogeneity, and local spatial diversity patterns expressed across the landscape. By utilizing spatial indices and satellite image processing in an integrated and synergistic manner, a major contribution of this study to the field of urban landscape fragmentation is that the assessment of urban expansion trajectories can be derived from the fragmentation indicator of a city landscape. We hope our results will prompt further urban studies and urban change detection because this is the first work to depict urban landscape fragmentation in Baqubah. The findings and all the analysis processes may help the municipality, urban planning departments, and decision-makers with proper planning to maintain the sustainability of the city's natural resources and planned urban growth.

5. Conclusions

Cities all across the world are widely dispersed. Sprawl as fragmentation, as opposed to sprawl as lower-density development, is now a universal feature of cities. Urban sprawl is the fragmentation of the built-up areas of cities by the open areas interpenetrating them. The main goals of this study were to assess the level of landscape fragmentation in Baqubah and evaluate the directions of its expansion trajectories. The technique we used to determine built-up areas uses publicly available medium-spatial resolution Sentinel-2 optical satellite imagery for a particular period of time. The methods and findings presented here include an indicator approach to quantify the fragmentation of built-up patches and the direction of their expansion in urban areas.

The investigation of urban landscape fragmentation revealed that the built-up area of Baqubah is dramatically fragmented. The decline in protected green and open space is a key factor in the rise of built-up land. According to an assessment of urban expansion trajectories, fringe areas also provide further possibilities for urban development and planning. The fragmentation levels in urban areas are difficult to assess empirically due to complex land-use patterns and a lack of land statistics from Baqubah Municipality. However, the findings show that 75% of Baqubah's built-up area is highly fragmented, and only 23% of the city's open space is located inside its urban limits. These main results contribute to our understanding of the dynamics of urban fragmentation in a variety of ways and serve as the foundation for the implementation of strategic planning priorities in the region. They may also be used as a benchmark for determining fragmentation in other cities and in urban studies.

Although the present study is one of the first attempts to examine the fragmentation of built-up patches thoroughly, some related factors should be considered in such studies. Therefore, an issue that was not addressed in this study was whether the related factors, such as city population size, levels of well-being, and topographical restrictions on expansion, have a role in formatting the extracted fragmented urban patterns. Notwithstanding the relatively limited statistical data and population census, this work offers valuable insights into situated land fragmentation patches. A great deal of further work is needed to determine the rate of fragmentation of land in the city. There is, therefore, a definite need to assess urban landscape fragmentation by employing satellite data for multiple time periods. Accordingly, a key policy priority should be to plan for the long-term care of urban sustainability by monitoring land transformation from green and open land to built-up areas.

6. Declarations

6.1. Author Contributions

6.2. Data Availability Statement

The corresponding author will provide the data used in this study upon request.

6.3. Funding

6.4. Acknowledgements

6.5. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] Kadhim, N., Mourshed, M., & Bray, M. (2016). Advances in remote sensing applications for urban sustainability. Euro-Mediterranean Journal for Environmental Integration, 1(1), 1–22. doi:10.1007/s41207-016-0007-4.

[2] Kowe, P., Mutanga, O., Odindi, J., & Dube, T. (2020). A quantitative framework for analysing long term spatial clustering and vegetation fragmentation in an urban landscape using multi-temporal landsat data. International Journal of Applied Earth Observation and Geoinformation, 88, 102057. doi:10.1016/j.jag.2020.102057.

[3] Angel, S., Parent, J., & Civco, D. L. (2012). The fragmentation of urban landscapes: Global evidence of a key attribute of the spatial structure of cities, 1990-2000. Environment and Urbanization, 24(1), 249–283. doi:10.1177/0956247811433536.

[4] Mitchell, M. G. E., Suarez-Castro, A. F., Martinez-Harms, M., Maron, M., McAlpine, C., Gaston, K. J., Johansen, K., & Rhodes, J. R. (2015). Reframing landscape fragmentation's effects on ecosystem services. Trends in Ecology and Evolution, 30(4), 190–198. doi:10.1016/j.tree.2015.01.011.

[5] Fahrig, L. (2003). Effects of Habitat Fragmentation on Biodiversity. Annual Review of Ecology, Evolution, and Systematics, 34, 487–515. doi:10.1146/annurev.ecolsys.34.011802.132419.

[6] Dubois, J., & Cheptou, P. O. (2017). Effects of fragmentation on plant adaptation to urban environments. Philosophical Transactions of the Royal Society B: Biological Sciences, 372(1712). doi:10.1098/rstb.2016.0038.

[7] Zambrano, L., Aronson, M. F. J., & Fernandez, T. (2019). The Consequences of Landscape Fragmentation on Socio-Ecological Patterns in a Rapidly Developing Urban Area: A Case Study of the National Autonomous University of Mexico. Frontiers in Environmental Science, 7(152). doi:10.3389/fenvs.2019.00152.

[8] Wei, Y., & Zhang, Z. (2012). Assessing the fragmentation of construction land in urban areas: An index method and case study in Shunde, China. Land Use Policy, 29(2), 417–428. doi:10.1016/j.landusepol.2011.08.006.

[9] Li, G., & Li, F. (2019). Urban sprawl in China: Differences and socioeconomic drivers. Science of the Total Environment, 673, 367–377. doi:10.1016/j.scitotenv.2019.04.080.

[10] Asabere, S. B., Acheampong, R. A., Ashiagbor, G., Beckers, S. C., Keck, M., Erasmi, S., Schanze, J., & Sauer, D. (2020). Urbanization, land use transformation and spatio-environmental impacts: Analyses of trends and implications in major metropolitan regions of Ghana. Land Use Policy, 96, 104707. doi:10.1016/j.landusepol.2020.104707.

[11] Li, F., Zhou, T., & Lan, F. (2021). Relationships between urban form and air quality at different spatial scales: A case study from northern China. Ecological Indicators, 121, 107029. doi:10.1016/j.ecolind.2020.107029.

[12] Benassi, F., Cividino, S., Cudlin, P., Alhuseen, A., Lamonica, G. R., & Salvati, L. (2020). Population trends and desertification risk in a Mediterranean region, 1861-2017. Land Use Policy, 95, 104626. doi:10.1016/j.landusepol.2020.104626.

[13] Su, S., Wang, Y., Luo, F., Mai, G., & Pu, J. (2014). Peri-urban vegetated landscape pattern changes in relation to socioeconomic development. Ecological Indicators, 46, 477–486. doi:10.1016/j.ecolind.2014.06.044.

[14] Dobbs, C., Nitschke, C., & Kendal, D. (2017). Assessing the drivers shaping global patterns of urban vegetation landscape structure. Science of the Total Environment, 592, 171–177. doi:10.1016/j.scitotenv.2017.03.058.

[15] Urbieta, P., Fernandez, E., Ramos, L., Méndez Martínez, G., & Bento, R. (2019). A land-cover based urban dispersion indicator suitable for highly dispersed, discontinuously artificialized territories: The case of continental Portugal. Land Use Policy, 85, 92–103. doi:10.1016/j.landusepol.2019.03.048.

[16] Ballantyne, M., Gudes, O., & Pickering, C. M. (2014). Recreational trails are an important cause of fragmentation in endangered urban forests: A case-study from Australia. Landscape and Urban Planning, 130(1), 112–124. doi:10.1016/j.landurbplan.2014.07.004.

[17] Li, F., & Zhou, T. (2019). Effects of urban form on air quality in China: An analysis based on the spatial autoregressive model. Cities, 89, 130–140. doi:10.1016/j.cities.2019.01.025.

[18] Li, F., Zheng, W., Wang, Y., Liang, J., Xie, S., Guo, S., Li, X., & Yu, C. (2019). Urban Green Space Fragmentation and urbanization: A spatiotemporal perspective. Forests, 10(4). doi:10.3390/f10040333.

[19] Sheng, N., Tang, U. W., & Grydehøj, A. (2017). Urban morphology and urban fragmentation in Macau, china: Island city development in the pearl river delta megacity region. Island Studies Journal, 12(2), 199–212. doi:10.24043/isj.25.

[20] Dai, S., Zuo, S., & Ren, Y. (2020). A spatial database of CO2 emissions, urban form fragmentation and city-scale effect related impact factors for the low carbon urban system in Jinjiang city, China. Data in Brief, 29, 105274. doi:10.1016/j.dib.2020.105274.

[21] Zuo, S., Dai, S., & Ren, Y. (2020). More fragmentized urban form more CO2 emissions? A comprehensive relationship from the combination analysis across different scales. Journal of Cleaner Production, 244, 118659. doi:10.1016/j.jclepro.2019.118659.

[22] Huang, X., Wang, Y., Li, J., Chang, X., Cao, Y., Xie, J., & Gong, J. (2020). High-resolution urban land-cover mapping and landscape analysis of the 42 major cities in China using ZY-3 satellite images. Science Bulletin, 65(12), 1039–1048. doi:10.1016/j.scib.2020.03.003.

[23] Zhang, Y., Shen, W., Li, M., & Lv, Y. (2020). Assessing spatio-temporal changes in forest cover and fragmentation under urban expansion in Nanjing, eastern China, from long-term Landsat observations (1987–2017). Applied Geography, 117. doi:10.1016/j.apgeog.2020.102190.

[24] Li, S., & Yang, B. (2015). Introducing a new method for assessing spatially explicit processes of landscape fragmentation. Ecological Indicators, 56, 116–124. doi:10.1016/j.ecolind.2015.03.031.

[25] Koroso, N. H., Lengoiboni, M., & Zevenbergen, J. A. (2021). Urbanization and urban land use efficiency: Evidence from regional and Addis Ababa satellite cities, Ethiopia. Habitat International, 117, 102437. doi:10.1016/j.habitatint.2021.102437.

[26] Yoo, C., Im, J., Cho, D., Lee, Y., Bae, D., & Sismanidis, P. (2022). Downscaling MODIS nighttime land surface temperatures in urban areas using ASTER thermal data through local linear forest. International Journal of Applied Earth Observation and Geoinformation, 110, 102827. doi:10.1016/j.jag.2022.102827.

[27] Ghosh, S., Kumar, D., & Kumari, R. (2022). Assessing spatiotemporal dynamics of land surface temperature and satellite-derived indices for new town development and suburbanization planning. In Urban Governance. doi:10.1016/j.ugj.2022.05.001.

[28] T. Ismael, N., Awda Mohammed, A., & Majeed Yas, S. (2020). Optimal Land Use Classification for Iraq Cities. Diyala Journal of Engineering Sciences, 13(1), 24–33. doi:10.24237/djes.2020.13103.

[29] Zha, Y., Gao, J., & Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. International Journal of Remote Sensing, 24(3), 583–594. doi:10.1080/01431160304987.

[30] Kadhim, N., & Mourshed, M. (2018). A shadow-overlapping algorithm for estimating building heights from VHR satellite images. IEEE Geoscience and Remote Sensing Letters, 15(1), 8–12. doi:10.1109/LGRS.2017.2762424.

[31] Vogt, P., Riitters, K. H., Estreguil, C., Kozak, J., Wade, T. G., & Wickham, J. D. (2007). Mapping spatial patterns with morphological image processing. Landscape Ecology, 22(2), 171–177. doi:10.1007/s10980-006-9013-2.

[32] Angel, S., Parent, J., & Civco, D. L. (2010). The fragmentation of urban footprints: global evidence of sprawl, 1990-2000. Lincoln Institute of Land Policy, Cambridge, United States.

[33] Angel, S., Blei, A. M., Parent, J., Lamson-Hall, P., & Galarza Sánchez, N. (2016). Atlas of Urban Expansion− 2016 Edition, Vol. 1: Areas and Densities. Lincoln Institute of Land Policy, Cambridge, United States.

[34] Wagtendonk, A. J., & Koomen, E. (2019). An indicator set for capturing long-term open space fragmentation and urban development dynamics. Computers, Environment and Urban Systems, 76, 178–193. doi:10.1016/j.compenvurbsys.2019.04.007.