Research Article

Monitoring Sustainable Land Use in Baghdad City with Multi-Temporal Satellite Images and Cloud Based Analysis Employing GEE and Remote Sensing

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Abstract: A multi-temporal Sentinel-2 and Landsat-8 analysis within Google Earth Engine (GEE) was conducted to analyze land use and land cover dynamics in Baghdad, Iraq. The NDVI-NDBI indices revealed that vegetation increased gradually, especially along the Tigris River and in rural areas, while urban expansion peaked around 2021 and slightly declined by 2024. There has been a reduction in degraded land and a partial stabilization of urban growth according to LULC maps. For rapidly growing cities like Baghdad, continuous monitoring and sustainable land-use planning are essential to balancing urban development and environmental preservation. Baghdad has experienced accelerated urban expansion over the last decade, placing increasing pressure on agricultural areas, natural vegetation, and ecological stability. This study applies a cloud-based methodology using NDVI and NDBI indices, annual composite generation, and automated image processing within GEE to quantify changes in vegetation cover, built-up areas, and land degradation across the city for the years 2018, 2021, and 2024. This research aims to examine the relationship between urban growth and vegetation dynamics, identify environmentally vulnerable zones, and support sustainable land-use policies in Baghdad. Results show a substantial increase in vegetation cover rising by approximately 55% in parallel with a slight decline in non-vegetated land. Urban expansion patterns observed in 2021 align with previous studies conducted, confirming the regional trend of increasing built-up surfaces. To enhance sustainability, the study recommends adopting precision agriculture and drip-irrigation systems to increase vegetative cover and reduce water loss, particularly in peri-urban districts highly affected by land degradation.

Keywords: Land Use and Land Cover change; Google Earth Engine; Urbanization; Baghdad city; Sustainable development.

1. Introduction

The preservation and sustainable use of land resources are one of the most important issues of the modern era, especially given the rapid growth of urbanization and socioeconomic development worldwide as preserving these resources requires integrated strategies combining technological tools, sustainable management practices, and long-term environmental planning [1]. Natural ecosystems and agricultural areas have suffered greatly as a result of excessive urbanization, which has upset the ecological balance and jeopardized environmental stability [2].

Ineffective land use planning and the misallocation of land resources have further jeopardized urban sustainability by hastening the conversion of agriculture into built-up areas and degrading the environment by raising carbon emissions, polluting the air and water, and causing soil erosion [3-5]. It is also important to enact effective farmland protection legislation because agricultural lands play a significant role in enhancing the social stability and food security [6], and also, better land management practices are noted to be an effective measure of mitigating the effects of climate change and ensuring sustainability of the environment [7]. Examples of activities caused by human beings include urban sprawl, population increase, deforestation and industrial expansion which have largely changed the face of the earth and natural resources. The pollution hotspots are increasingly being found in large cities, and this has considerably changed LULC patterns [8]. Changes in LULC are frequently causing of rising land surface temperatures (LST) and worsening ecological conditions that have a direct effect on biodiversity, air quality, and human well-being [9-11]. Therefore, continuous LULC monitoring is essential for understanding urban expansion, managing land resources, and lowering environmental pollutants [12, 13].

In this sense, Baghdad, the capital of Iraq, is an intriguing case study for examining how rapid urbanization affects developing cities. The spatiotemporal changes in land use and land cover have resulted in a significant shift in Baghdad; such as acceleration of rise in urban structure, reduction in agricultural areas as well as green spaces, therefore leading to the disruption of the local air quality and the increase in the intensity of the environment-related pressure, which makes quantitative measurements and systematic monitoring of changes in land use and land cover of the city's extensive importance [14, 15]. Geographic information systems (GIS) and remote sensing are effective measurements to evaluate the dynamics of such processes due to the ability to identify and quantify changes in land use and land cover over location and time. In Baghdad specifically, previous studies have reported significant reductions in vegetation and increases in built-up areas, confirming the urgent need for accurate multi-temporal monitoring [14-16]. Satellite imagery could create spectral indices which are important pointers of urban growth and health of vegetation, e.g., the Normalized Difference Built-Up Index (NDBI), and the Normalized Difference Vegetation Index (NDVI), respectively [17]. To strengthen comparative analysis, this study also considers NDMI (Normalized Difference Moisture Index) as a supplementary indicator that can support NDVI in detecting moisture-related vegetation stress. These indicators have become important in assessing the state of ecology and promoting ecological urbanization. The ability of Google Earth Engine (GEE) and other cloud-based computing platforms to process and analyze large volumes of multi-temporal satellite data at previously unheard-of spatial and temporal scales will now be possible. To strengthen comparative analysis, this study also considers Normalized Difference Moisture Index (NDMI) as a supplementary indicator that can support NDVI in detecting moisture-related vegetation stress. GEE gives the ability to analyze satellite images automatically when it comes to sensors such as Sentinel-2 and Landsat-8, which can be useful in environmental surveillance as well as sustainability check-up [18, 19]. The investigations conducted in the past have proved the efficiency of these methods to assess the changes in the large cities environments, particularly in Iraq [15, 16]. With this in mind, the purpose of the present research is to explore the spatiotemporal dynamics of the land cover land use in Baghdad, especially the correlation between the urban expansion and the vegetation change. The study uses NDVI, NDBI, and multi temporal imaging as a part of the GEE model to evaluate the vegetation dynamics, detect urban development trends, and support sustainable land-use planning interventions. The results of the presented work support evidence-based decision-making for environ mental management as well as sustainable urban expansion in fast-growing cities, such as Baghdad. In remote sensing, NDVI is a widely utilized metric to assess and monitor the health, density, also intensity of plant cover in a given area.

NDVI is computed using satellite images taken in a variety of spectral bands, especially visible and near-infrared regions of electromagnetic spectrum [20].

$$NDVI = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \tag{1}$$

In contrast to the Near Infra-red (NIR) region, the NDBI identifies urban areas with increased reflectance in the shortwave-infrared (SWIR) region. Positive NDBI values generally indicate urban or built-up areas, while negative values correspond to vegetation or open land. The GEE platform provides an efficient environment for computing NDBI directly from Sentinel-2 surface reflectance data.

$$NDBI = \frac{\text{SWIR(Band11)} - \text{NIR(Band8)}}{\text{SWIR(Band11)} + \text{NIR(Band8)}} \tag{2}$$

The Landsat data archive enabled multidecadal LU LC monitoring at global extent and medium (30 m per pixel) spatial resolution. For all thematic products except water, we used the spatiotemporally consistent Landsat GLAD ARD inputs available as the source data for global LCLU mapping [21].

2. Materials and Methods

2.1. Study Area

Geographically located in the country's center, Baghdad is bounded by the governorates of Salah Al-Din, Anbar, Babylon, Wassit, and Diyala as shown in Figure 1. The city is situated inside a vast alluvial plain that the Tigris River created, dividing Baghdad into two main areas: Al-Karkh on the west and Al-Rusafa on the east. Geographically, Baghdad covers an area of around 870 km² between latitudes 33°25′–33°44′ N and longitudes 44°16′–44°29′ E. Baghdad's physical organization shows a dense urban core centered in the central districts, encircled by rural outlying areas that progressively lose urban intensity as one move toward the city's periphery. The summertime climate of the city is usually hot and dry, with an average of high temperatures of 48 °C in July and August. On the other hand, winters are damp and chilly, with daytime highs of about 10 °C on average [22].
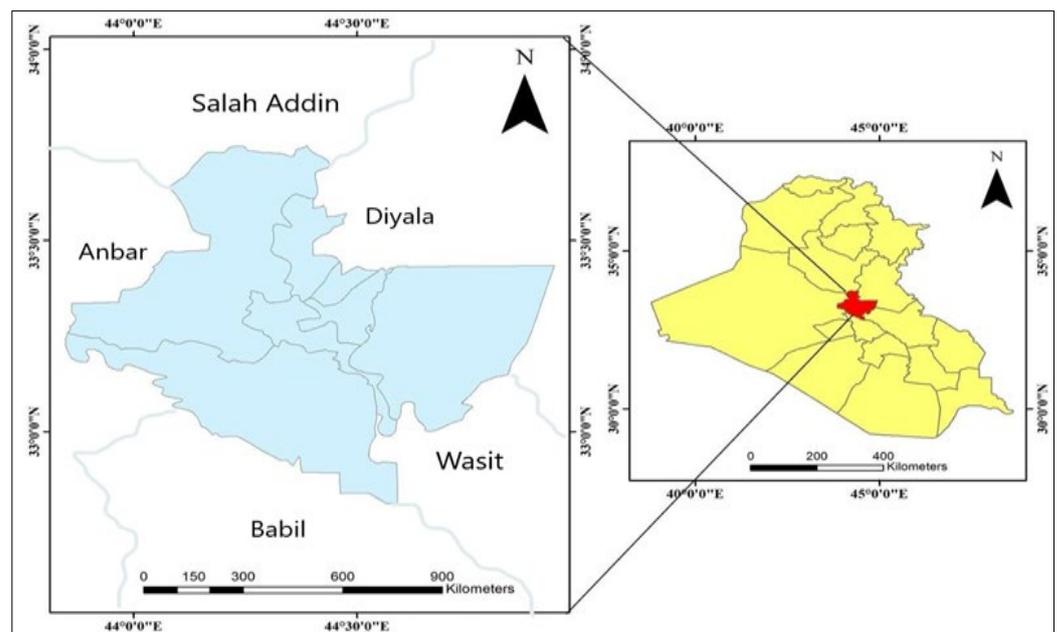
Figure 1. Baghdad map showing the location of the study area.

2.2. Data Collection and Processing

The Landsat-8 OLI created by the United States Geological Survey is capable of providing nine spectral bands starting with the visible spectrum to the SWIR regions, whereas Sentinel-2, a product of the European Space Agency, provides 13 spectral bands with increased spatial and temporal resolution that can be used to map vegetation and urban areas in more detail [23, 24]. The dataset was done with the help of GEE platform which utilizes Python and Ja- JavaScript API to facilitate the effective administration of data and large-scale calculation. Temporal changes were assessed by using satellite data of 2018, 2021 and 2024. It was done by determining the limits of the study area, applying cloud masking filters, and quality control filters, and finally by compiling images in the entire region to create annual composite datasets. Finally, the results were enhanced and demonstrated with the help of ArcGIS 10.8 raster functions which were used to produce and visualize spectral indices dynamically. Remote sensing and cloud-based geospatial processing technologies have also been a useful combination to carry out the environmental analysis and sustainable urban monitoring. Studies such as Amani et al. [25]. emphasize the importance of these types of platforms such as GEE in facilitating the multi-source data integration process, automatic development of indices, and the spatial trend analysis of LULC and vegetation on a large scale.

3. Results

The analysis of the NDVI showed that there might be considerable spatiotemporal changes in vegetation cover across the zone under the study. To enable effective analysis of the plant dynamics and surface land changes, the results were divided into three main indices namely NDVI, LULC, and NDBI.

3.1. NDVI

In NDVI maps, green colored regions depict agricultural and vegetated lands, which are a measure of the overall ecological well being and the agricultural productivity of the area. It is important to monitor these areas so as to manage the resources, plan the agricultural policy and conduct sustainability assessments. Although the large urban areas revealed minimal or no growth, the statistics revealed a slight increase in the green cover especially in the rural areas and those around the Tigris river.

Table 1 and Figure 2 present the NDVI values for each year of observation. An analysis of vegetation index trends during the study period Figure 3 shows that the year 2018 recorded the lowest NDVI levels, indicating reduced vegetation cover at that time. Despite this, subsequent years exhibited noticeable improvement in vegetation density. It is interesting to note that the largest increase in vegetation cover in 2018 was observed in the Al-Adhamiya district, whereas in 2024 the Al-Mahmoudiya region recorded the highest increase in vegetation cover, as illustrated in Figure 4. The overall variation and temporal change in vegetation index values throughout the study years are clearly demonstrated in Figure 5, highlighting a general upward trend in vegetation cover across the study area. Furthermore, Table 2 and Figure 6 summarize the estimated percentage increase in vegetation cover for each district, revealing significant spatial variability in vegetation growth rates. These findings are consistent with previous studies that reported similar vegetation recovery associated with improved irrigation practices and localized greening initiatives in central Iraq. Additionally, the observed increase in vegetation cover aligns with recent regional climate stabilization, particularly following enhancements in water-management infrastructure.
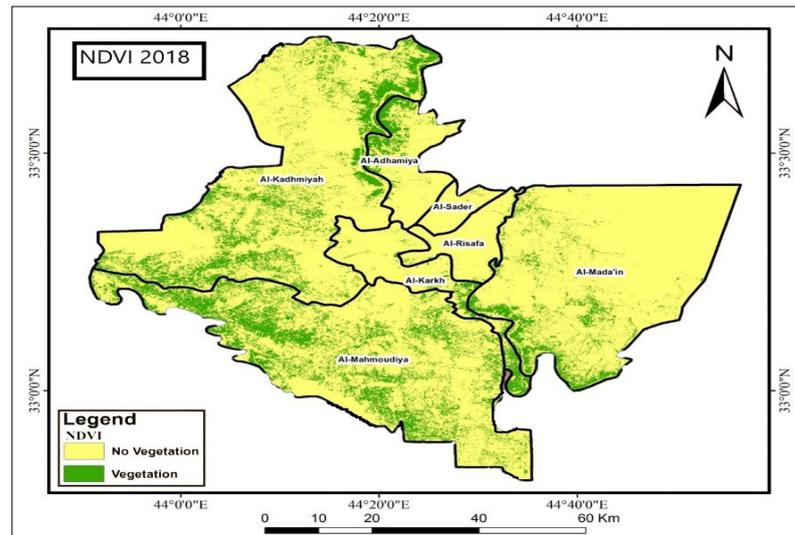
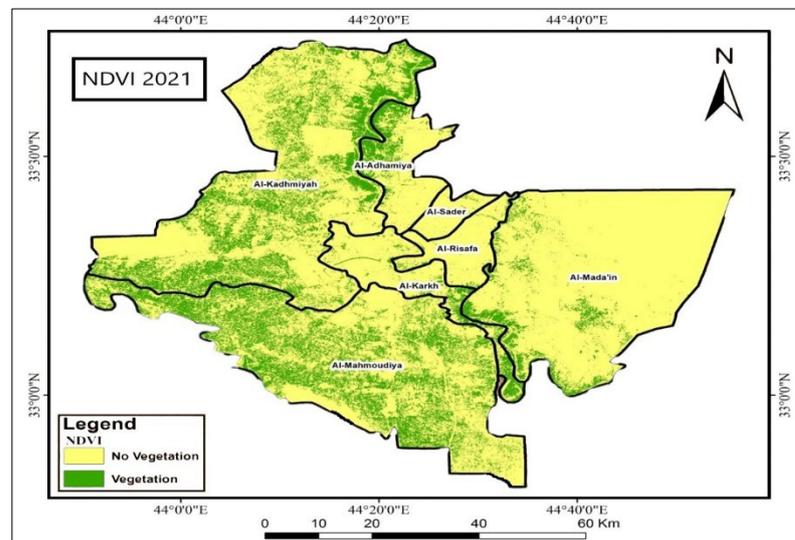**Figure 2.** Baghdad Vegetation Index (NDVI) in 2018.

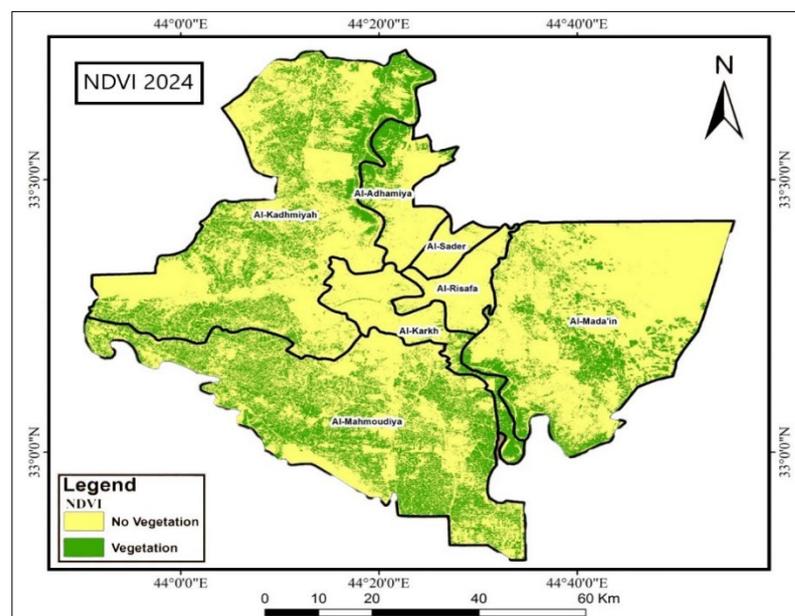**Figure 3.** Baghdad Vegetation Index (NDVI) in 2021.

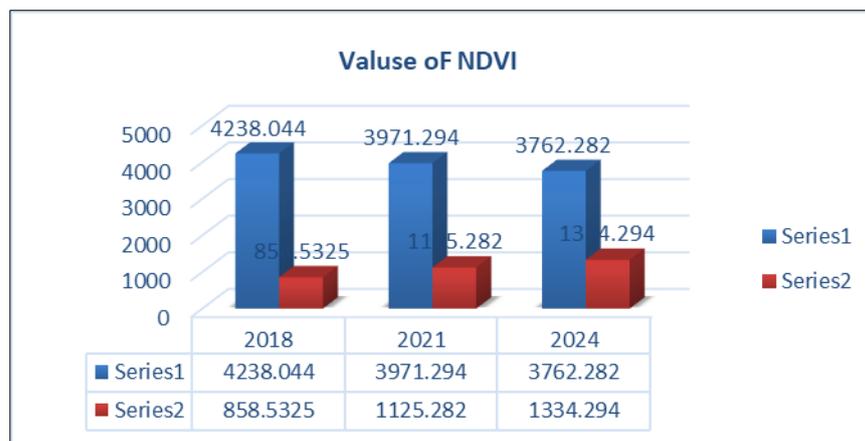**Figure 4.** Baghdad Vegetation Index (NDVI) in 2024.

**Table 1.** The Values given by the vegetation cover index.

Description	Year		
	2018	**2021**	**2024**
Non-vegetation area	4238.04	3971.29	3762.28
Vegetation area	858.533	1125.28	1334.29

Figure 5. Change in vegetation index values during the study years.

Table 2. Estimated percentage increase in vegetation cover by region.

Area	Vegetation cover percentage (%) 2018	Vegetation cover percentage (%) 2024	Percentage increase (%)
Al-Kadhmiyah	20%	45%	25%
Al-Adhamiya	25%	50%	25%
Al-Sader	10%	20%	10%
Al-Risafa	12%	22%	10%
Al-Karkh	18%	35%	17%
Al-Mahmoudiya	30%	65%	35%
Al-Mada'in	15%	38%	23%
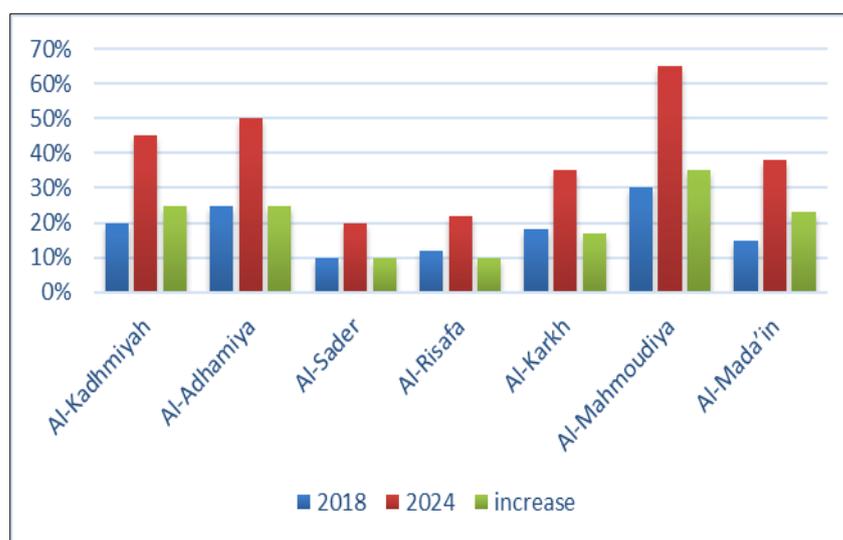
Figure 6. Estimated percentage increase in vegetation cover by region.

3.2. LULC

The outcomes of the LULC classification exhibited varying patterns of geographical arrangements which depicted a dynamic interaction between natural and man-made land changes. The pink and peach colors on the maps indicate areas that are barren or sparsely vegetated which are usually associated with land degradation, soil exposure, or excessive human actions such as development and overgrazing. To arrange sustainable development and land restorations, these areas should be determined. White-colored areas, which symbolize urban and constructed zones depict the current urbanization of Baghdad. The patterns can be analyzed to determine the trends of urban growth, requirements in the infrastructure, and solve problems in the urban planning. Figures 7 and 8 reveal the increased urban growth coupled with reductions in barren land, particularly along riverbanks where vegetation regeneration has intensified. The observed contraction of barren zones around the Tigris River corresponds with localized afforestation efforts and agricultural reclamation programs implemented during 2021–2024, as supported by similar findings in regional LULC studies. This pattern demonstrates a shift toward improved ecological management, likely influenced by government-led urban greening campaigns.
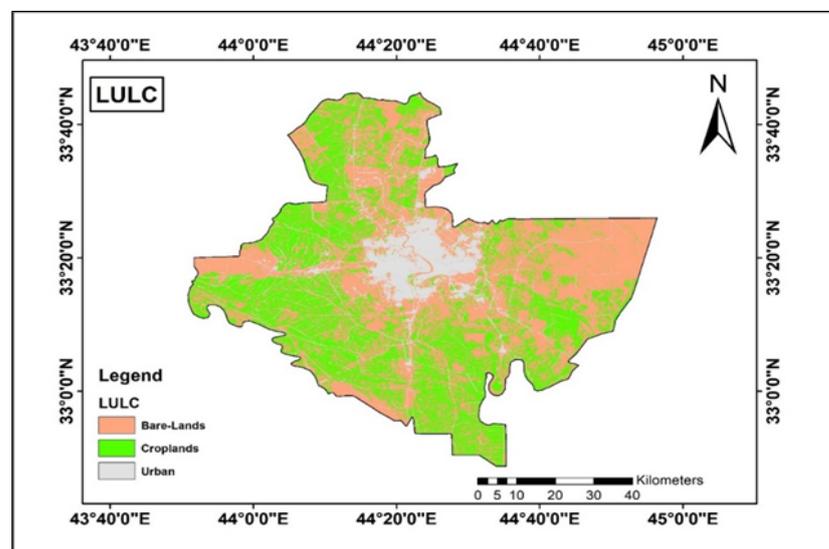

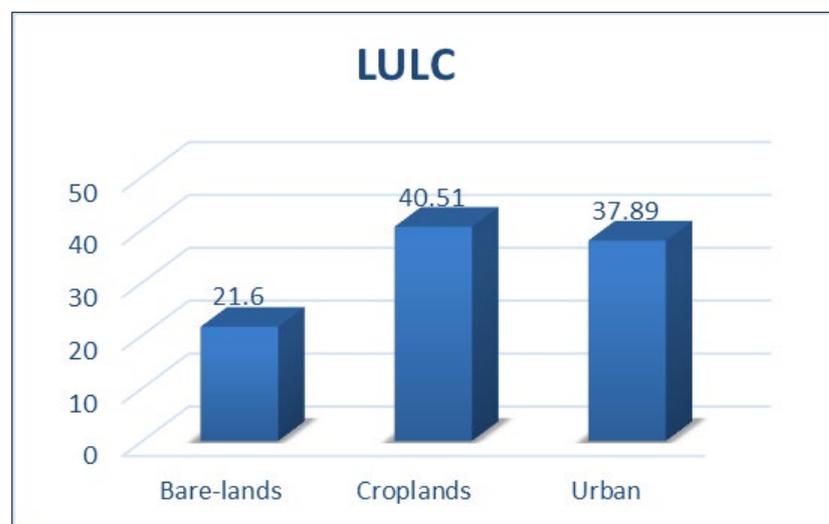**Figure 7.** Baghdad Land use /Land cover.

Figure 8 . Contrast Baghdad Land use /Land cover.

3.3. NDBI

The conclusions offered by the NDBI shed more lights on the urbanization processes and the increase in the built-up areas. In the paper, it is demonstrated that the disparity between the SWIR and NIR reflectance is an efficient method to map built-up surfaces, the higher NDBI, the higher the urbanized area and the lower the NDBI value, the more likely is to be covered by vegetation or water. The high concentration of NDBI values (orange to red) in the eastern and southeastern regions in 2018 was due to the higher level of urban activity and development. On the other hand, the Tigris River and the agricultural regions showed low or negative NDBI (green to blue colors), which points to the presence of vegetated or water-rich surfaces. Figures 9 and 10 show that in 2021, intermediate NDBI values (yellow- green tones) were more widespread, which means that land-use change was replaced by urban expansion. Peri-urban regions experienced slight reduction in the intensity of high NDBI values as compared to 2018 which indicate a partial stabilization of urban growth. In 2024, it could be observed that the high NDBI values declined, whereas medium to low NDBI values increased, and orange-red zones became smaller, as observed in Figure 11. This trend can be the sign of better vegetation recovery, reforestation programs, or a temporary halt of urbanisation in some areas. Combined, the NDVI and NDBI measurements can be used to gain a complete picture of the vegetation dynamics, urban development and land changing trends of Baghdad. They also demonstrate the direct impacts of restoration programs, weather patterns as well as urban growth policies on the alteration of land surface over time. This decline in NDBI values is likely associated with temporary halts in construction, post-crisis land reclamation activities, and new irrigation projects that reinforced vegetation regrowth in rural districts.
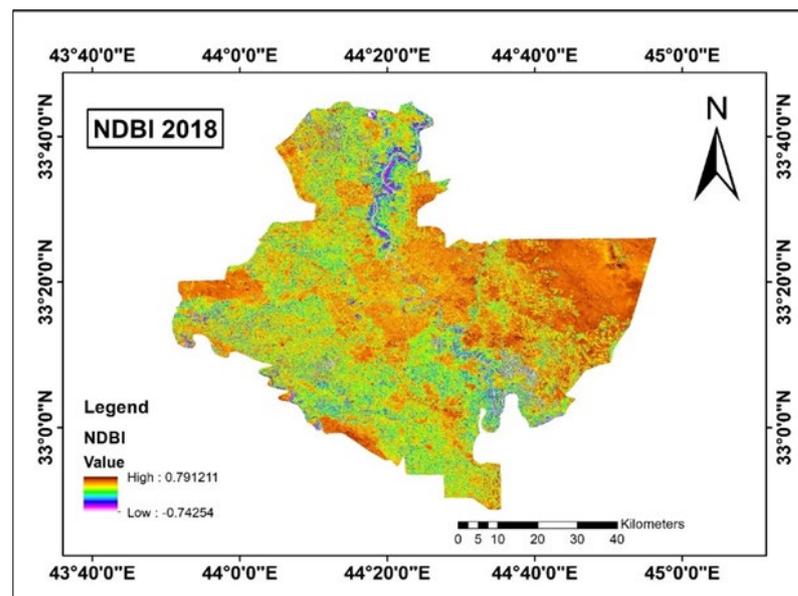

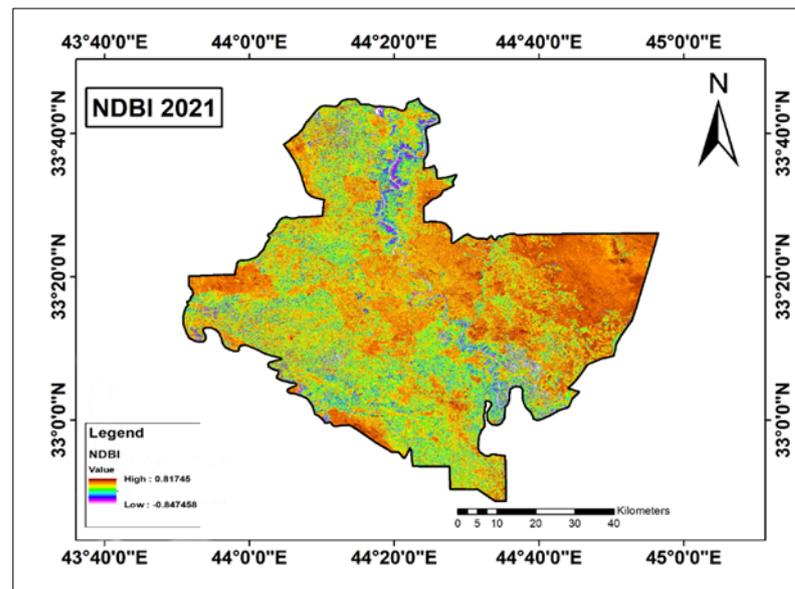**Figure 9.** NDBI values, Baghdad in 2018.

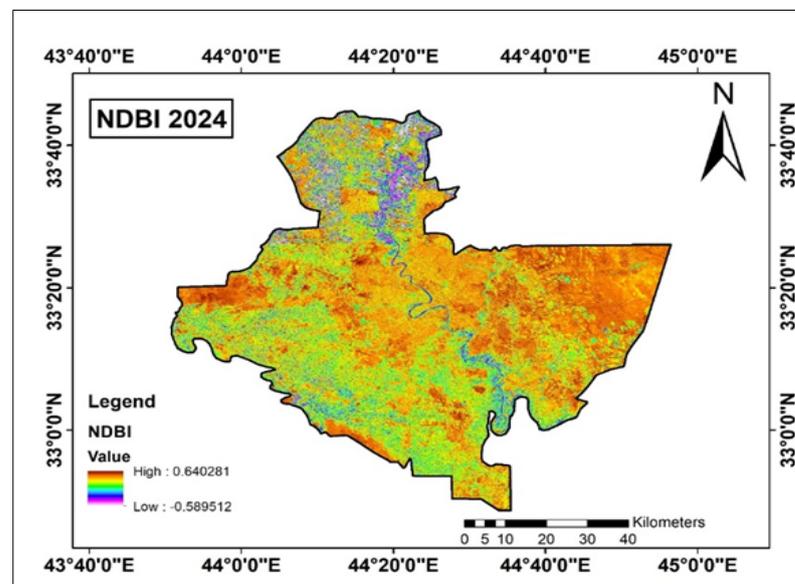**Figure 10.** NDBI values, Baghdad in 2021.

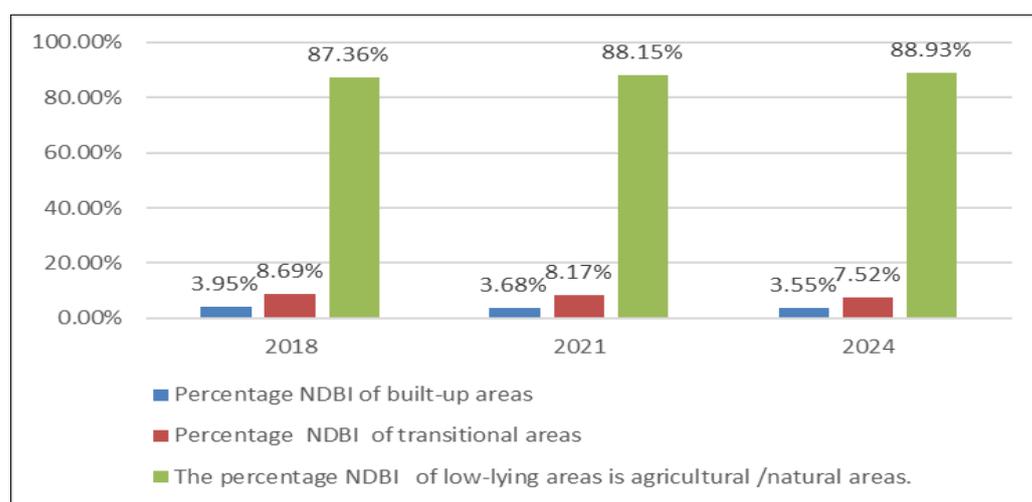**Figure 11.** NDBI values, Baghdad in 2024.

Table 3 shows the percentage change in the urban cover index, whereas Table 4 highlights the range and variability of NDBI values during the three observation years. According to the comparison research, 2021 had the greatest NDBI values, followed by 2018, while 2024 had the lowest, most likely as a result of the start of temporary land reclamation operations and new residential building projects have shown in Figuer 12. These results correspond with regional studies that reported slowed urban expansion following 2020 due to economic changes and increased environmental regulations in Baghdad.

Table 3. The highest and lowest values during the three years of study and the range of variation.

Year	NDBI High	NDBI lowest value	Range
2018	+0.7912	-0.7425	1.5337
2021	+0.8174	-0.8474	1.6648
2024	+0.6403	-0.5895	1.2298

Table 4. Estimated percentage increase in the urban cover index for three years.

Year	Percentage NDBI of built-up areas	Percentage NDBI of transitional areas	The percentage NDBI Many of the low-lying areas are agricultural/ natural areas.
2018	3.95%	8.69%	87.36%
2021	3.68%	8.17%	88.15%
2024	3.55%	7.52%	88.93%

Figure 12. contrast, estimated percentage increase in the urban cover index for three years.

Altogether, the NDVI and NDBI estimations are a good way to understand the dynamics of vegetation in Baghdad, the urbanization process, and the patterns of land transformation and show the direct influence of the restoration project, climate conditions and urbanization of the area and development policies on the alteration of the land surface.

4. Discussion

The results derived from NDVI, NDBI, and LULC analyses demonstrate a strong interaction between vegetation dynamics and rapid urban expansion in Baghdad. The observed 55% increase in vegetation cover between 2018 and 2024 corresponds with a partial reduction in non-vegetated land, indicating the positive effects of localized restoration initiatives and increased agricultural activities, particularly in periurban areas. Similar vegetation recovery patterns have been reported in several cities within arid and semiarid regions, suggesting a broader regional trend toward gradual ecological improvement under targeted landmanagement practices. Urban expansion reached its maximum extent in 2021, reflecting accelerated housing development and largely uncontrolled land conversion processes. This trend is consistent with patterns observed in rapidly growing cities where population pressure and limited regulatory enforcement drive horizontal urban growth. The relative stabilization observed by 2024 may indicate the early influence of urban containment measures or a shift toward densification strategies, a phenomenon increasingly documented in cities transitioning toward more sustainable planning frameworks. In terms of indicator performance, NDVI and NDBI proved to be effective tools for capturing vegetation cover and builtup area dynamics. Nevertheless, the inclusion of additional indices such as NDMI could enhance the detection of vegetation stress and moisture variability, particularly in arid environments where sparse vegetation and soil background effects can limit index sensitivity.

To promote vegetation sustainability within urbangrowth zones, several strategies are recommended, including the adoption of green roof systems, the development of urban tree belts, and the application of efficient irrigation methods such as drip irrigation in peri-urban agricultural areas. Furthermore, limiting horizontal urban expansion through vertical zoning and compact development policies can reduce land degradation pressures. Collectively, these approaches align with naturebased urban development frameworks that emphasize the integration of ecological processes into longterm sustainable city planning.

5. Conclusions

The combined analysis of the NDVI, NDBI, and the LULC data based on the Sentinel-2 and Landsat-8 images using the GEE platform offers useful information about the dependence between the urban development and environmental transformation in Baghdad. Although urbanization is a continuing process, the vegetation cover has demonstrated a stable increase between 2018 and 2024, with the non-vegetated areas reducing by 4,238 to 3,762 km^2, and the vegetated areas growing by 858 to 1,334 km^2, i.e. by approximately by 55%. This portrays the good effects of reforestation, urban greening and improved management of water resources. In the meantime, NDBI outcome shows that the most dramatic urban growth processes have been observed in the eastern and southeastern areas of the city, followed by the trend of stabilization after 2021, presumably because of the successful urban planning efforts or a decline in construction activities. These results establish that remote sensing data including NDVI and NDBI are effective parameters that can be employed in tracking land-use, urban growth, and assessing the environmental effects associated with the same. The general findings point the need to incorporate sustainable city planning and environmental conservation so as to have a balanced and robust urbanization in Baghdad. Meanwhile, NDBI results reveal that the most intense urban expansion occurred in the eastern and southeastern parts of the city, followed by a stabilization trend after 2021, likely due to effective urban planning initiatives or a slowdown in construction activities. These findings confirm that remote sensing indices such as NDVI and NDBI are powerful tools for monitoring land-use change, tracking urban expansion, and evaluating associated environmental impacts. The overall results emphasize the importance of integrating sustainable urban planning and ecological preservation to ensure balanced and resilient urban development in Baghdad.

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