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ASSESSMENT OF URBAN VEGETATION CHANGES ON DIFFERENT SCALES IN A SEMI-ARID REGION USING SATELLITE IMAGERIES: A CASE STUDY OF ERBIL CITY, IRAQ

Thesis of Ph.D. Dissertation

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1 Introduction and Objectives

One issue that emerges as crucial for the quality of life in urban areas is the vegetation area or green fields. These areas provide relaxation and entertainment opportunities to the citizens as well as they become essential to address climate issues. In the last decades, the pressures on vital ecosystem functions have increased rapidly due to the expansion in the global population, higher demand for land consumption, and the robust urbanization process. So, both the rate of urbanization and the loss of vegetation are two interrelated developments rapidly increasing across the world (Weng et al., 2004; Liu, Y. et al. 2015). The rise of urban areas is one of the factors supporting climate change, and in return, cities can be significantly affected by climate change. More volatile heat and rain patterns can put significant constraints on the city infrastructures as well as the life quality of its citizens, including air pollution. In this setup, green fields emerge as an essential measure to address climate change challenges in the cities. Poor planning and lack of enough vegetation area can lead to the problem of Urban Heat Island (UHI) effects (Arnfield, 2003). Then, it is possible to use vegetation to reduce the impact of UHI. The vegetation cover is also known to affect the social and physical environment in more than one way (van den Bosch & Ode Sang, 2017). The influence of urban greenery to the quality of human life considered aspects of better air quality, stress reduction, and even social contacts (Grimmond, 2007; Carrus et al., 2015). The lack of vegetation can alter many types of environmental conditions such as climate change, biodiversity, and the quality of water and air. Then, higher levels of vegetation area, as well as its optimal spatial distribution over the city, would balance some of the adverse climate change effects and limit the environmental costs of cities. Therefore, the proper measurement of vegetation area and the assessment of its spatiotemporal distribution are essential inputs in the urban planning and development policies and studies.

The main aim of this research is to utilize different remote sensing data and sensors at different spatial resolutions (from large to small) to study and analyse the spatial and temporal patterns of the vegetation cover in the city of Erbil. The study further attempts to use these data to characterize and discuss the influence of urbanization in the city on the spatial distribution and the temporal dynamics of the vegetation cover. Then it evaluates the usefulness and the suitability of the applied land surface data as a means to study vegetation cover from a temporal and spatial perspective. So, the goal of the research project is to provide a comprehensive picture and understanding of the urban vegetation dynamics in the last decades, to examine the factors affecting these dynamics, and to assess the access of citizens to the green areas in the city limits. Within this context, three objectives mentioned as follows:

First objective: To investigate the spatiotemporal variation of urban vegetation cover in the city and its surroundings using the MODIS sensor and examine its relation to climate conditions. In this objective, the following research questions that addressed below:

How did the spatiotemporal variation of urban vegetation cover in the city and its surrounding area measured by the MODIS sensor in the last decades, and how is it related to climate conditions?

How did urbanisation impact the vegetation and quasi-natural (grassland) vegetation in the city and its surroundings?

Second objective: To study the spatiotemporal variation of urban greenness cover in the city limits and examine the role of urban expansion, using Landsat satellite data. In this objective, the following research questions that addressed below:

What is the influence of urbanisation on the temporal dynamics and spatial distribution of vegetation cover in the last decades inside the city limits?

Third objective: To provide a detailed analysis of urban greenness distribution for particular city districts using Pleiades satellite data in the last decades and examine the access of city dwellers to green areas. In this objective, the following research questions that addressed at the following:

How the urban greenness distributed within a particular district of the city, and what is the level of greenness access to city dwellers?

One can also construct relevant hypotheses for the three research objectives and questions in the context of the city of Erbil as follow:

The first hypothesis stated as H1: Spatiotemporal variation of urban vegetation cover in the larger city area is related to the climate conditions.

The second hypothesis can be put forward as H2: The spatial and temporal changes in the urban vegetation in the city of Erbil have a close association with the urban expansion.

The third hypothesis stated as follows: H3: The spatial distribution of urban vegetation worsened over time in terms of the access of the habitants to green areas within feasible distances.

2 Study Area and Methodology

The study area for this research is the city of Erbil and its surroundings. Erbil is the capital of the Iraqi Kurdistan Region, and it is the central city in northern Iraq (Figure 1). It lies between longitudes 43° 51' 20", 44° 12' 28" and latitudes 36° 05' 58", 36° 15' 54". It is 412 m above mean sea level, covering an area around 572 km^2. The population of Iraqi Kurdistan is around 5.2 million people, while the population of Erbil city increased by 210%, from 485,968 in 1987 to 1,025,000 in 2011 (Ministry of Planning, 2014).

The research process involves the use of satellite imagery taken from MODIS, Landsat, and the Pleiades. The temporal scale covers 25 years from 1990 to 2015. The spatial scale involved dividing the study area into three levels, which are looked at in greater detail below, and which reflect different levels of proximity and analysis. These enable a better understanding of distribution and localization in terms of urban change and vegetation cover over time (Figure 2).

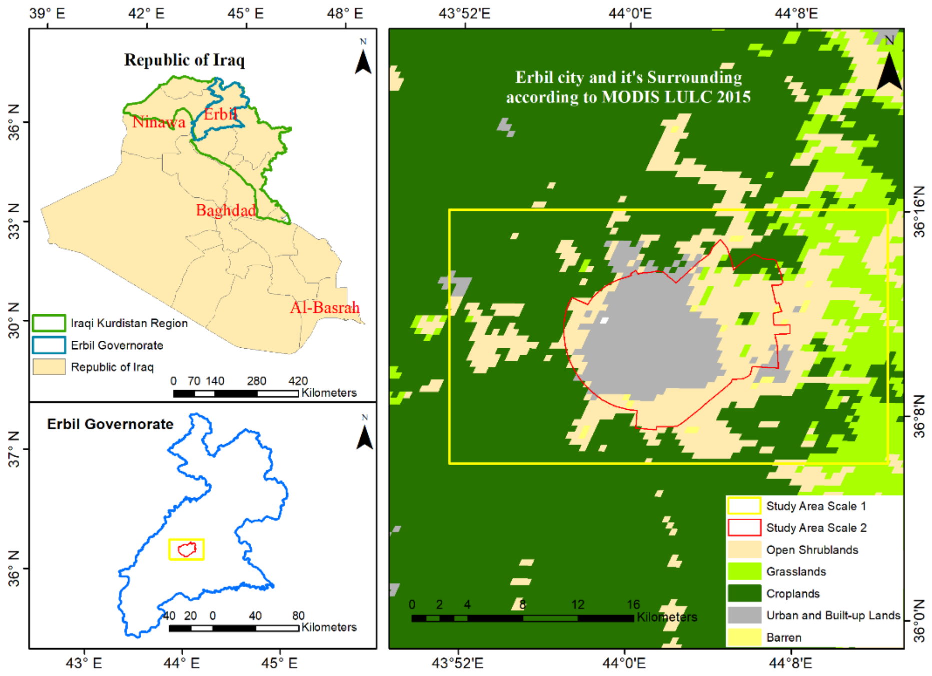

Figure 1: Overview of Erbil City and its Surroundings

Scale 1 in the below graph is the most significant section of the scale, covering an area of 572 km^2, and it is similar to the city in terms of natural characteristics, it selected to identify the impact of urbanisation on vegetation cover. The data extracted to analyse the dynamics of vegetation cover surrounding the city of Erbil and the effects of urbanization in these areas. Scale 2, which is the most dynamic area affected by human activities, covering an area of 140 km^2. The data uses to analyse the spatial-temporal variations of vegetation dynamics and built-up areas. Scale 3 represents a sample of the city that investigates evaluate the spatial distribution of vegetation cover, covering an area 24 km^2.

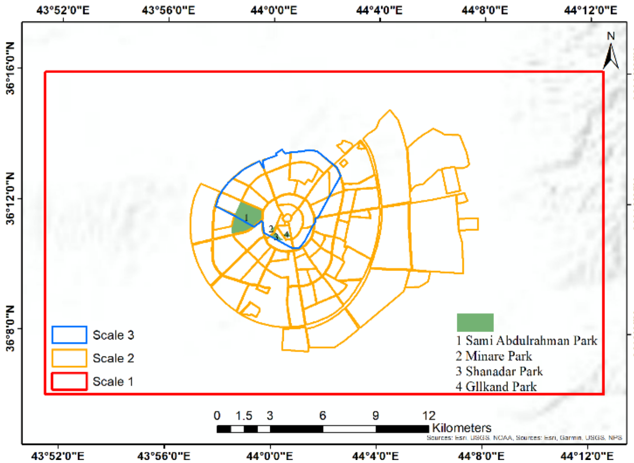

Figure 2: Levels of Spatial Scales in the Study Area

2.1 Scale 1: MODIS vegetation indices and Land Cover

The MODIS vegetation indices. The mean values of NDVI and EVI indices generated to identify temporal variations from 2000 to 2015, using 2-3-year time intervals, with methods involving NDVI and EVI time series analysis and land use classification in 250 m spatial resolution. Second: MODIS Land Cover Type Yearly L3 Global 500m resolution (MCD12Q1), Land Cover Type 1 Annual International Geosphere-Biosphere Programme (IGBP) classification global vegetation classification scheme with five global land cover classification systems. Open Shrubland, Grassland, Cropland, Urban/Built-up area, and barren or spare vegetation. The 16 single image investigated, for each year into one image. MODIS land cover used to carry out change assessment and distribute NDVI and EVI into land cover classes by using zonal statistical table technique.

In the case of the MODIS method, the processing flow-chart is given in (Figure 3). Pre-processing of satellite data was required and conducted in the study. Data pre-processing included checking pixel reliability and vegetation index quality. Bad pixels are omitted from the analysis as they represent clouds, cloud shadows. Mean NDVI and EVI generated to provide an average index over the complete study area, allowing the comparison between years to examine a temporal trend. Plots of monthly NDVI and EVI statistics (mean, minimum, maximum, and standard deviation) are generated from 2000 to 2015, identifying temporal variations.

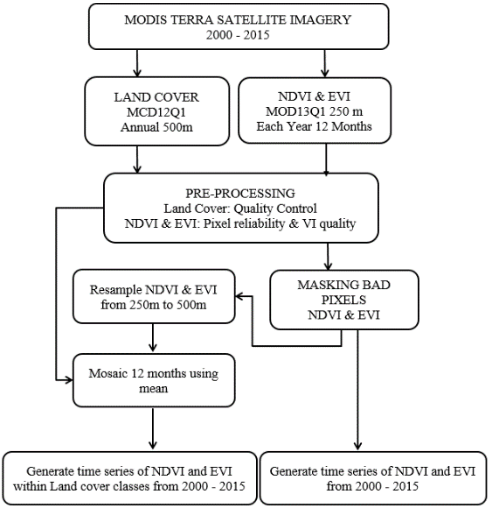

Figure 3: Pre-Processing and Processing of MODIS Satellite Imagery Data at Scale 1

2.2 Scale 2: Landsat Satellite data and multispectral classification

A set of six cloud-free Landsat images used in the analysis. The data ordered in Science Research and Development (LSRD). Pre-progressing such as image enhancement, geometric correction, and atmospheric correction already corrected by LSRD. To avoid seasonally derived errors, to use scenes only in the summer months, which represent the same vegetation condition. Also, the selection of specific periods reflects spatial distributions and temporal changes due to significant economic and urban development.

In the case of Landsat imagery data, a four-step framework is used in the analysis, as presented in (Figure 4). Step one involved the use of the MLC and the LSMA methods to classify image pixels. In the second step, the results from the LSMA fuzzified to extract the land-use classes, after which both LSMA and MLC results undergo a classification accuracy assessment, which must be greater than 80% for the classification to use in the analysis. In the third step, the determined magnitude of green vegetation change. Then, in the last step, vegetation indices are extracted to generate statistics (mean, minimum, maximum, and standard deviation) and create maps to determine spatial-temporal variations. These steps are repeated for 5-year intervals starting from 1990 and finishing in 2015.

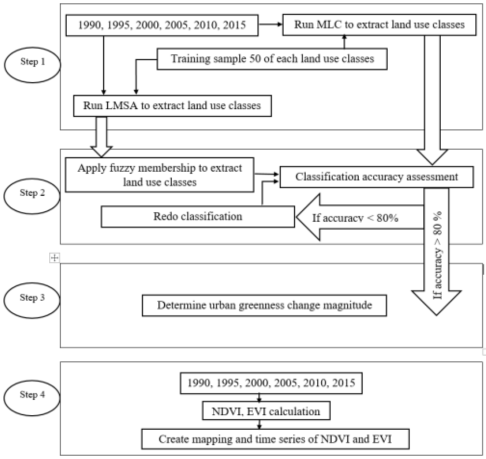

Figure 4: Pre-Processing and Processing of Landsat Satellite Imagery Data at Scale 2

2.3 Pleiades very High-resolution Imagery and Multispectral Classification

This study utilized very high resolution and cloud-free multispectral satellite data. Data requested on 21st June 2015. The data delivered in the ORTHO form. The Pleiades deliver high spatial resolution 0.5 m panchromatic and 2 m multispectral bands (blue, green, red, and infrared. The satellite images used to produce detailed vegetation maps at a section of Erbil city (Hussein et al., 2019). The year is the same as the last image of MODIS and Landsat (2015).

A series of processing steps applied to prepare the satellite images for further analysis (Figure 5). First, the MLC method used to assign the digital pixel values of the satellite images into different land cover classes. In supervised classification, training data collected by drawing boundaries around areas that are representative of the land cover types meant to map in the image. After these steps, the image divided into four classes concerning the main objectives of this study. These classes are bare land, water, vegetation, and built-up land areas. Second, the NDVI measures, to establish whether the variation between city districts in terms of vegetation cover is significantly different, the analysis of variance (ANOVA) is performed. Third, to examine visually how the city districts are different NDVI box plot technique was employed using mean and standard deviation. Furthermore, the percentage of each land cover class was extracted and compared for further analysis, such as comparing with Landsat results.

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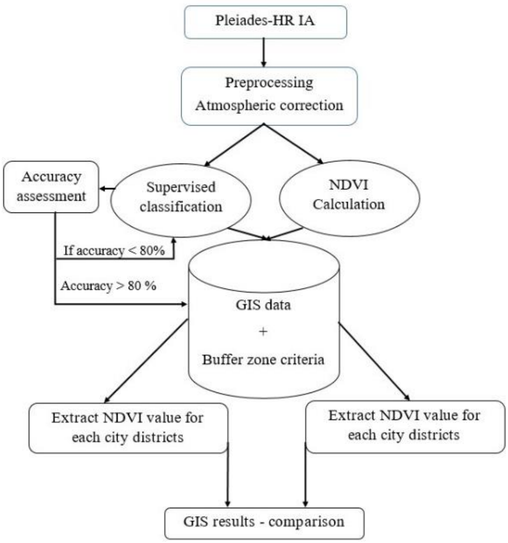

Figure 5: Pre-Processing and Processing of Pleiades Satellite Imagery Data at Scale 3

3 Results

3.1 Monitoring Spatiotemporal Variation of Urban Vegetation Cover Using MODIS Satellite Data

3.1.1 Temporal Trends

One of the striking features from the plots is the monthly pattern within the years. The NDVI and EVI indexes usually starts the year with a value of around 0.2-0.3 and 0.1-0.2 respectively and then reach the highest value of the year during two months of March and April, where the index values can reach the levels of 0.4 to 0.5 for NDVI and 0.3.5 to 0.4 for EVI (Figure 6). Then, indexes fall to the lowest values within the year during summer and autumn months and stand on the level between 0.1-0.2 for NDVI and 0.5-0.1 for EVI during June and November, while it might experience a slight increase at the end of the year.

The within-month pattern of vegetation index correlated with the humidity NDVI and EVI with values of 0.92 and 0.94 in April and rainfall NDVI and EVI levels with values of 0.64 and 0.62 in April.

When some broad comparisons made across years for the NDVI and EVI indices, it is seen that 2003 and 2015 stand out as greener years, while 2008 was a notably less green year in the sample (Figure 7).

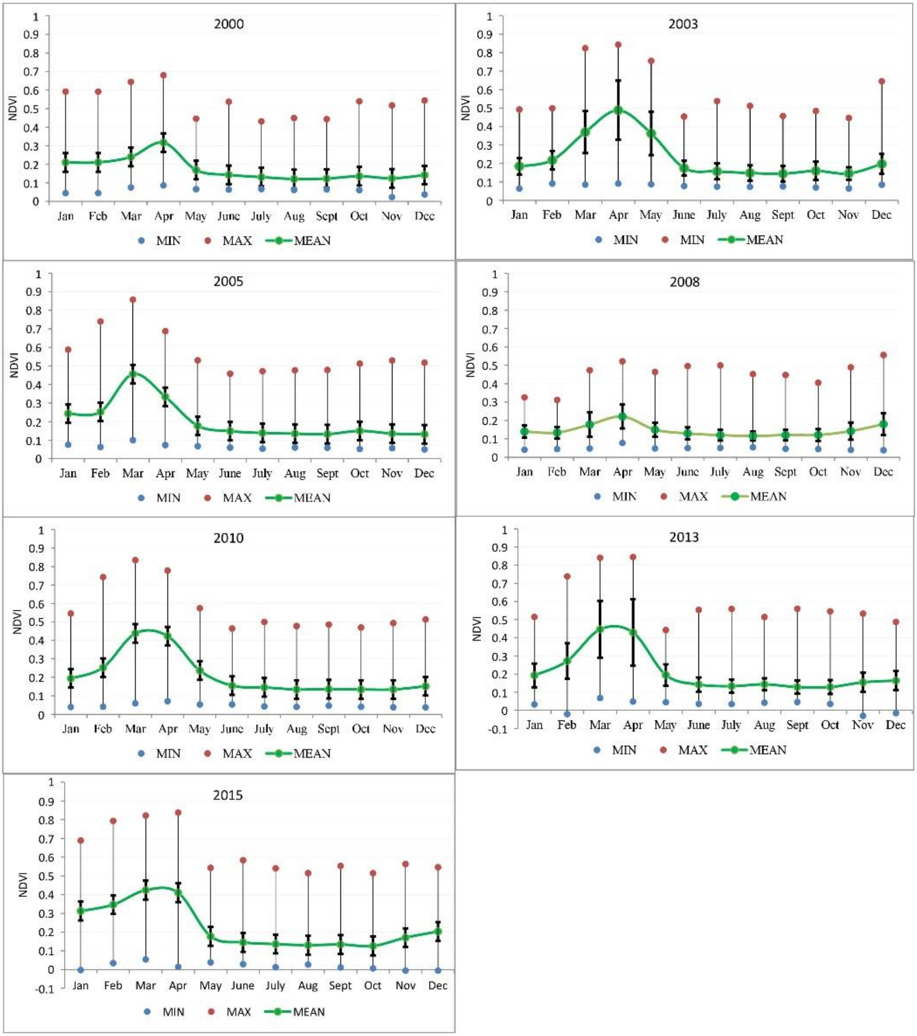

Figure 6: NDVI Monthly Summary Statistics for 2000–2015

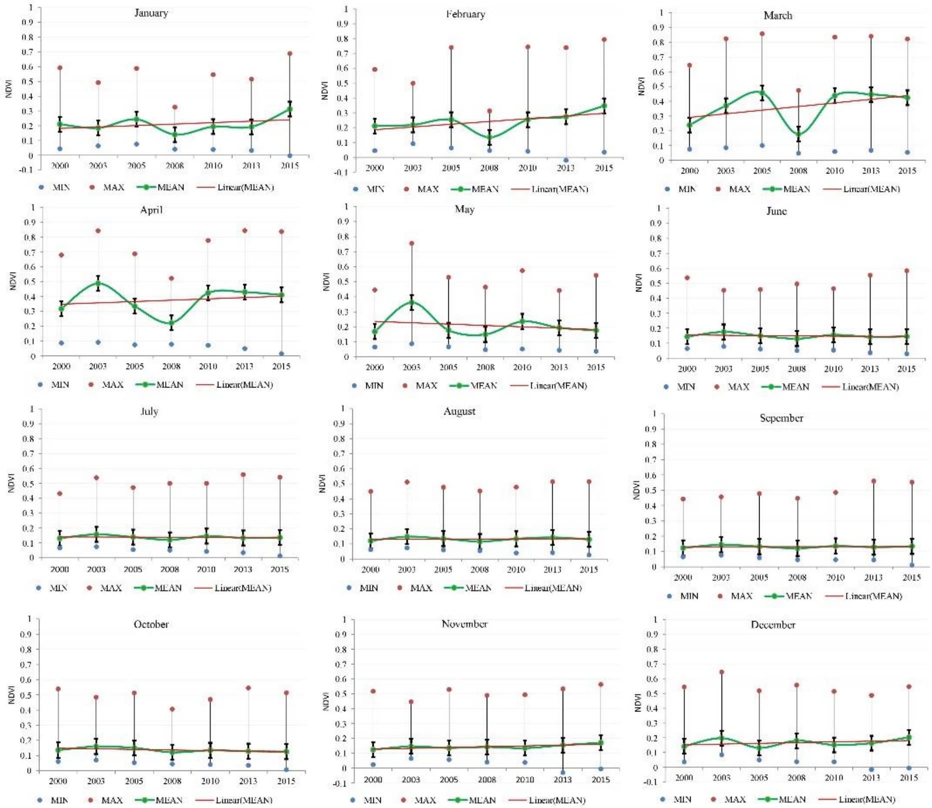

Figure 7: Monthly plots of NDVI Summary Statistics for 2000–2015

3.1.2 Spatiotemporal Variation

Figure 8 presents visualize the spatiotemporal variation of vegetation from April 2000 to April 2015 for NDVI measures. April is chosen as the comparison month as it had the highest vegetation growth, and as a result, it would best represent differences in true vegetation coverage extent.

It is evident from the maps that the spatial distribution of urban areas and/or barren or sparsely vegetated areas with values less than 0.25 has expanded over the past 16 years. However, this growth did not happen in a linear way. The sample years of 2003 and 2015 were relatively green years, while 2008 was the least green year. When the initial year of 2000 and the final year of 2015 compared, it showed that there is a decrease in the SVIs measures, especially within the city limits.

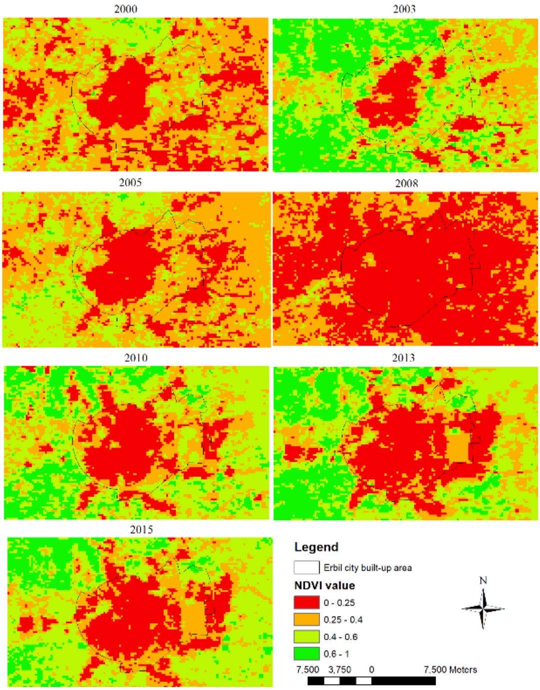

Figure 8: April NDVI Raster Time-Series of Erbil from 2000 to 2015

Consequently, vegetation surrounding the urban center replaced by urban growth. The EVI imagery has displayed a large area of poor vegetation health, which is more likely in the semi-arid regions of Iraq. The variation in vegetation distribution in the city of Erbil and its surrounding areas is a consequence of the following factors: the significant increase in built-up land, the constructions of green spaces such as parks; reducing vacant land; reducing agricultural land until almost to zero value.

3.2 Spatiotemporal Variation of Urban Greenness Cover using Landsat Imagery

The results of the MLC classification showed that land cover types displayed a significant change in the sample years covering the period of 1990–2015 (). As an important finding, the share of built-up land increased significantly from 24% in 1990 to 58% in 2015. This development is closely related to the rising population and the increasing urbanisation rates in the city of Erbil (KRG, 2015). Figure 9 shows that the rising share of build-up land happened at the expense of bare land and agricultural land. The share of the built-up area increased by 34% points, while the share of bare land decreased by 24% points, and the share of agricultural land decreased by 8% points between 1990 and 2010. The agricultural land had a share of 8% as of 1990 and decreased gradually to 2005, while its share disappeared totally as of 2010. Regarding the green vegetation area, it displayed little difference between 1990 and 2015, as the total green vegetation area was 889 ha in 1990 and 815 ha in 2015. That means that the area remained unchanged and did not keep pace with other levels of land use growth. However, its share first declined to 2.7% in 2005, and its share increased back to 6% in 2015. So, the urban expansion affected the green vegetation area negatively in the 1990–2005 period, while with the construction of green areas by the local administration government (KRG, 2015), the green vegetation area recovered back in the 2005–2015 period.

Both MLC and LSMA spatiotemporal distribution of land cover types display very similar dynamics. Significant changes have taken place in the land use classes. Built-up land grew slowly from 1990 to 2000 and extended from the north-east to the south-west. According to KRG (2015), this is due to low internal migration, whether rural to urban or urban to urban, due to economic and political crises. Then it increased rapidly to 2015, and the city expanded in different directions. The reasons were the lifting of UN sanctions after 2003 and a stable security situation, which stimulated economic growth and expansion in construction (KRG, 2015). Evidently, as of 1990, there existed dispersed green vegetation areas within the city limits as well as sizeable agricultural land in the surroundings of the city. However, over time, agricultural land disappeared totally, and the green vegetation became more concentrated in certain parts of the city. The most noticeable change in vegetation land occurs around the urban centre and main roads in 2000 and 2005, which can be explained by the subsequent increase in spatial extension and seasonal drought. As discussed by Hussein (2018), the construction of Sami Abdulrahman Park, covering around 200 ha or close to 50% of green vegetation as of 2010 in LSMA method, was instrumental in the concentrated increase in the share of green vegetation in the city.

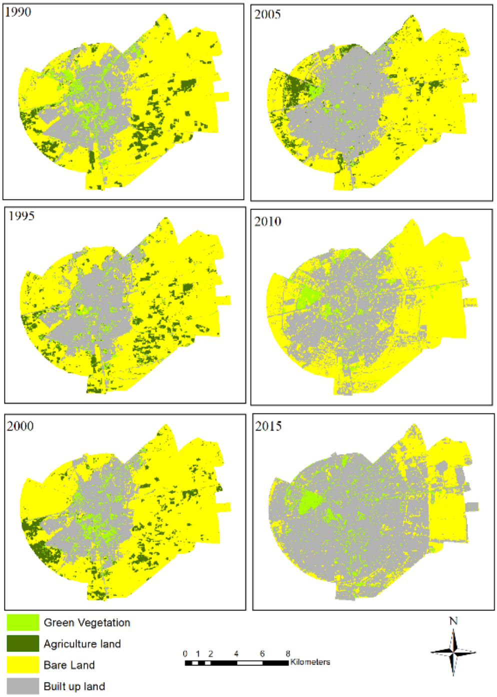

Figure 9: MLC Spatiotemporal Variation of Land Cover Type

3.2.1 Spatiotemporal Variation of Urban Vegetation Cover Derived from Vegetation Indices

Landsat imagery data used to construct the EVI and NDVI, similar to MODIS imagery data. Table 1 presents the estimated values for both indices covering the period of 1990–2015 at five-year intervals. The table indicates that the mean EVI measure declined from 0.114 in 1990 to 0.080 in 2015, and the mean NDVI measure declined from 0.137 to 0.113 in the same period. The table 1 also, show that the biomass of vegetation remains low with a value of less than 0.2 according to Landsat SVIs data. The mean of EVI and NDVI started at the highest value in 1990 and decreased gradually to dip in 2005, then increased gradually to 2015. Overall, vegetation indices showed a gradually decreasing trend from 1990 to 2015.

Table 1: EVI & NDVI results from Landsat Imagery

SVIs year	Min	Max	Mean	STD
EVI 1990	0.007	0.605	0.114	0.048
EVI 1995	0.074	0.632	0.102	0.048
EVI 2000	0.015	0.461	0.076	0.027
EVI 2005	0.076	0.425	0.060	0.025
EVI 2010	0.095	0.489	0.088	0.045
EVI 2015	0.147	0.802	0.080	0.051
NDVI 1990	0.008	0.673	0.137	0.059
NDVI 1995	0.130	0.682	0.132	0.059
NDVI 2000	0.020	0.472	0.090	0.030
NDVI 2005	0.082	0.435	0.070	0.028
NDVI 2010	0.180	0.523	0.112	0.052
NDVI 2015	0.452	0.857	0.113	0.072

3.3 Spatial Distribution of Vegetation Cover in Erbil City Districts Using High-Resolution Pleiades Satellite Imagery

3.3.1 Results of Land Use Land Cover by Pleiades Imagery

The results of the supervised classification highlighted that most of the districts, which are 69% urban land, following this, bare land covers an area of 17%. However, the ratio of the vegetation land cover is only 14%. In addition some districts have very high vegetation areas, such as Sami Abdulrahman Park having 44% vegetation share, Zaniary with 38% vegetation share, Taajeel with a 22% share and Brayaty 21%

vegetation share. However, half of the districts have less than 10% vegetation area (Figure 10).

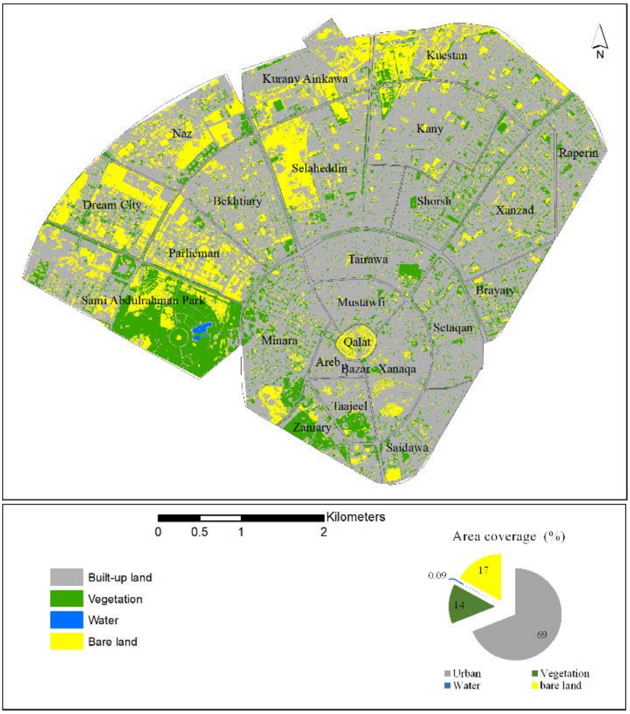

Figure 10: Land Cover Classes according to Pleiades Imagery

3.3.2 Spatial Distribution of Vegetation Indicator using NDVI

The districts located close to the city center, such as Mustawfi, Tairawa, Setaqan, and Bazar show the lowest green space compared to the other city districts. The possible reason for this finding might be related to the history of these areas because Erbil is one of the oldest cities in the northern part of Iraq due to having an ancient castle at its center. Over its history, the city has expanded in a circular shape around the castle. Therefore, the older districts, which are close to the castle, have a very low proportion of green space due to the lack of available land. Built-in or built-up areas have low values of mean NDVI 0.16 and 0.074. In the new build districts like Dream city and Naz, still, NDVI values are low (Figure 11). This result is in line with our classification result, as it shows that those new build districts have more bare lands compared to other places in the city. This spatial distribution confirms the previous finding that green vegetation is distributed very unevenly across districts.

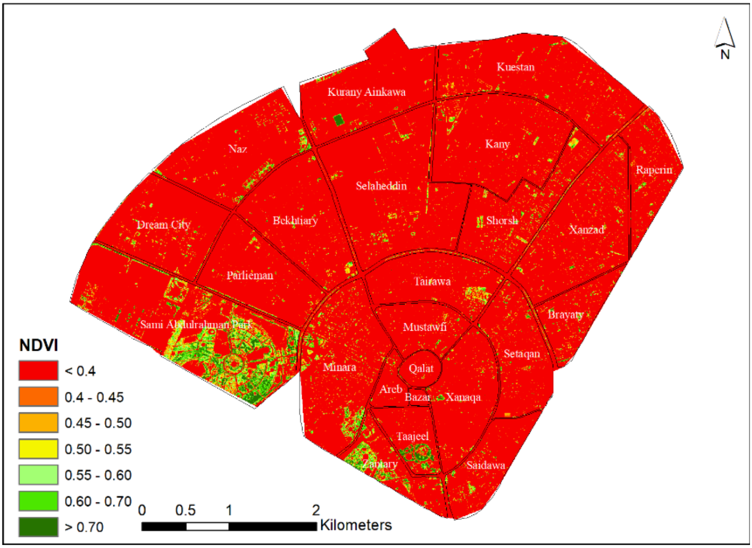

Figure 11: Spatial Distribution of NDVI Measure

3.4 Green Space Access Results

The green access within 300 m is minimal in most districts except the surroundings of Sami Abdulrahman Park. Moreover, 4 districts have zero access within the 300m buffer zone, while four of these also have zero green access within a 2km buffer zone. These values imply that green vegetation areas unevenly distributed within the city limits. The most significant results indicate the 42% of districts have access to 2 km and more than one 300 m buffer zone, 7 of them such as Taajeel, Zaniary, Areb, Sami Abdulrahman Park, Minara, Bekhtiary, and Parlieman have 100% access (Figure 12).

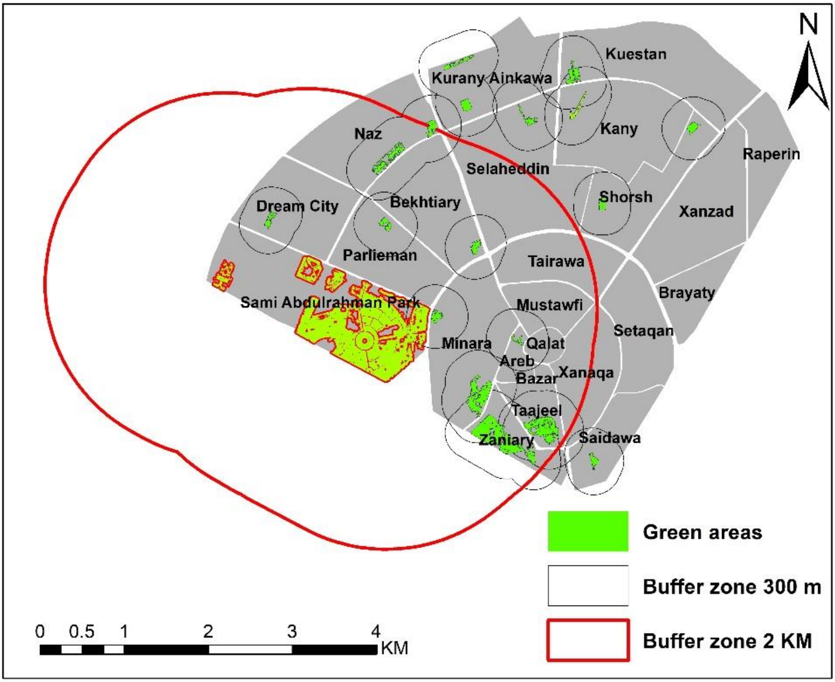

Figure 12: Buffer Zone of Green area in the Districts

4 Comparison of MODIS, Landsat, and Pleiades in 2015

Finally, one can compare three satellite imagery data at the same time, in addition to bivariate comparisons. In this context, Figure 13 shows the min, maximum, and average values of NDVI measure with MODIS, Landsat, and the Pleiades. It is seen that for this vegetation index, MODIS and Landsat do not produce different average values, with both estimating an index value of around 0.14.

In contrast, Pleiades has a higher average value with 0.16. In addition, the difference between the minimum and maximum values widens from MODIS to Landsat to the Pleiades. These results imply that the Pleiades has much more reliable and robust identification when studying smaller scales like the city districts.

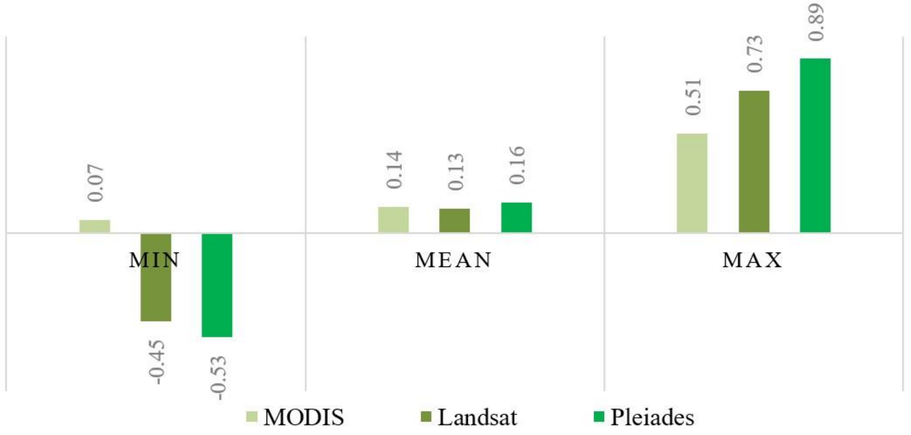

Figure 13: Comparison of MODIS, Landsat, and Pleiades NDVI in 2015

One can also make a comparison between Landsat and Pleiades results. Figure 14 shows that the Pleiades has much finer documentation of surface types as it can focus on smaller scales more effectively. In contrast, Landsat has more coarse identification of land uses. The Pleiades can identify small spots of green areas within the urban lands and around streets, where the average size of paths was 0.010 hectare and for Landsat was 0.94 hectare. So, there are many tiny green areas in the map for the Pleiades, while such areas were usually identified on Landsat images as a built-up place.

Figure 14: Spatial Comparison of Landsat MLC, LSMA, and Pleiades Land Uses in 2015

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