Urban expansion of Baghdad city and its impact on the formation of Thermal Island based upon Multi-Temporal Analysis of satellite images

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Abstract. The research deals with the thermal island in Baghdad city and the effect of urban expansion on it. Cities are suffering from a marked rise in temperature, compared with the surrounding rural areas, this problem occurs in most cities of the world. The reason for their formation is the increasing of human activity in the form of city components, such as buildings and roads that replace green spaces and open spaces. This means that most of these materials have the ability to absorb solar radiation and convert it into heat energy that increases the heat of their environment. Remote sensing technique is used to determine the thermal island through using Landsat satellite images as well as the use of GIS technology in mapping and analysis of spatial variation for thermal island. Normalized Difference Vegetation Index (NDVI) is calculated to extract vegetation cover from 2003 to 2018. The land surface temperature is estimated from the thermal band of satellite images for the same period. The change in vegetation cover is linked to the change in land surface temperature to determine the effect of vegetation cover degradation on surface temperature, also to determine the relationship between thermal island and land uses. The values of NDVI was high in 2003 and it ranged from (-0.714 - 0.693); this indicates a high vegetal cover, while its value is decreased to (-0.22 - 0.509) in 2018, pointing out to the significant deterioration of vegetation cover in 15 years. The land surface temperature is increased from (10.93-36.26) in 2003 to (22.62-50.29) in 2018; all this at the expense of converting the green, open and agricultural areas to residential, commercial and industrial uses as well as the large number of random settlements that appeared in Baghdad after 2003.

1. Introduction

The land of Mesopotamia is described as "black ground" to indicate the high productivity of these lands due to their physical and chemical conditions and high fertility due to the availability of suitable water sources for agricultural production [1]. However, as time has passed, especially in recent decades, these lands have had degradation. The deterioration has especially resulted due to the accumulation of salt in them, poor management, climate change, urban expansion as well as water scarcity [2]. Degradation of vegetation can be defined as a change in the components, the structure and the geographical distribution of vegetation including the destruction, the removal or the introduction of alien and harmful species. This change is often gradual and can be inferred through the environmental indicators [3]. The removal and the destruction processes include change in any form of vegetation.
such as trees, shrubs and grasses. The agricultural land in Iraq is one of the most important natural and economic resources; the problem of deterioration in agricultural land is one of the most serious problems facing the land in Iraq, especially in Baghdad. Vegetation cover is all plants on the Earth surface like trees, bushes or wild plants that originated naturally, which is one of the most important environmental components. It is the lung from which the Earth breathes and is the food source for all living organisms [4]. Green areas, as the lung of city, have great climatic importance and have a key role in maintaining ecological balance by reducing contaminants in the city atmosphere, especially carbon dioxide (CO₂). So, green areas are formed as one of the basic needs in the city of Baghdad because of their role in improving the local climate [5]. Monitoring of vegetation degradation requires continuous and comprehensive data for the area to be studied with the development of remote sensing technology and satellite images. Several plant indicators have been developed and calculated using remote sensing data which indicate plant growth, density and susceptibility to disease depending on the radiation reflection values by vegetation.

2. Methods and Materials

This section presents the spatial and temporal boundaries of the study area and performs the digital process on satellite images.

2.1. Boundaries of the study area

Baghdad is the capital of the Republic of Iraq, the largest city in Iraq and the second largest city in the Arab world; it is situated between latitudes 33.452° and 33.184° N, and longitudes 44.189° and 44.576° E as shown in Figure1. The importance of the geographical location of Baghdad lies in the availability of Tigris River’s water, reduced risks of flooding which in turn led to the expansion of the city and increased its influence, as well as in its easy connectivity across the Tigris River by bridges. Today, the city consists of 27 districts which are divided into several sub-districts. The climate of Baghdad is hot and dry in summer, cool and humid in winter, and the weather in Spring and Autumn is pleasant despite their shortness. The average temperature between May and September reaches 40 °C, and in July and August, the temperature reaches 40 °C, while in winter the average temperature during the day is 10 °C, and sometimes reaches to freezing. Rainfall lasts from December to April with an average annual precipitation of 150 mm. In spring and early summer, the northwest wind blows causing sandstorms. In recent years, especially after the US invasion of Iraq in 2003, air pollution and atmospheric carbon in the country has increased due to generator exhaust, increased desertification, decreased agriculture land, and open areas [6].

2.2 Data used and working method

Satellite data (Landsat 5-8) with sensors (TM and OLI) were downloaded from USGS website (https://earthexplorer.usgs.gov). To identify changes in vegetation cover, satellite images were selected for two different years for the purpose of analysing and studying the state of vegetation. The first image of Landsat 5 is in 2003 and the second image from Landsat 8 is in 2018 with (Path 168-Row 37), Table (1) shows the Satellite data used in the research.

After obtaining the images, some digital processing and geometric correction of the satellite images were carried out using GIS 10.6 and ERDAS 2014 programs to prepare the visualizations for the process of analysis and classification of vegetation. In addition, the conversion of digital values (DN) into radiance values and then to reflectance values was done. The subset of the study area from the entire is shown in Figure 2.
Figure 1. Location of the study area.

Table 1. Type and specification of the satellite data used in the study

| Rank | Satellite type | Sensor | Date      | Resolution |
|------|----------------|--------|-----------|------------|
| 1    | Landsat 5      | TM     | 2003/3/22 | 30         |
| 2    | Landsat 8      | OLI    | 2018/3/18 | 30         |

Figure 2. (a) Satellite image of the study area in 2003, (b) Satellite image of the study area in 2018
2.3 Satellite image analysis
After performing the digital processing on the satellite images, analysis on satellite data is applied by calculating the vegetation index to identify and estimate the changes in vegetation cover during the study period which is linked to the change in the surface temperature from the thermal band of satellite images by the following steps:

2.3.1 calculation of NDVI. To estimate the state of vegetation degradation in the study area, the Normalized Difference Vegetation Index is calculated to extract the vegetation cover from the rest of the other cover by using the NDVI equation. This indicator is calculated by performing the difference ratio between the Near-infrared band and Red band where plants have high reflectivity in the range of near-infrared wavelength and low reflectivity in the range of red wavelength as in the following equation [7].

\[
\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})} \quad \ldots (1)
\]

2.3.2 Calculation of land surface temperature. To extract the land surface temperature from the satellite image, it has used the thermal band represented by band six for Landsat 5 and band ten for Landsat 8 for both sensors (TM, OLI). The first step of calculating the land surface temperature is to convert the digital values of satellite image to spectral radiation values. Which is based on spectral radiation values (minimum and maximum values), that are taken from the Metadata file of satellite sensor type [8], then the radiation values are converted into temperatures as in the following equation [8]

\[
L_{\lambda} = \left[\left(L_{\text{max},\lambda} - L_{\text{min},\lambda}\right) / Q_{\text{cal},\lambda}\right] \times Q_{\text{cal}} + L_{\text{min},\lambda} \quad \ldots (2)
\]

Where:
- \(L_{\lambda}\) is the spectral radiation in \([\text{mW cm}^{-2}\text{sr}^{-1}\text{\mu m}^{-1}]\).
- \(L_{\text{max},\lambda} - L_{\text{min},\lambda}\) is the spectral radiation for each range as their values are extracted from the Metadata file with the satellite image.
- \(Q_{\text{cal}}\) is the value of the digital number of spectral bands of the sensor.
- \(T = \frac{K_2}{\ln\left(\frac{K_2}{T_\lambda} + 1\right)}\) \quad \ldots (3)

Where: \(K_1\) and \(K_2\) are constants values that vary with the type of sensor from the Metadata file.

3. Results and Discussion
Normalized Difference Vegetation Index has been used to identify the vegetation cover patterns and other cover types that exhibited values close to the spectral reflectivity of plant and affected the accuracy of the results. Figure 3 shows NDVI values for the images of study area in 2003 and 2018. Table 2 shows the highest and lowest values of the NDVI. Unsupervised classification is applied to the images as shown in Figure 4. The area of vegetation cover is calculated for each image as shown in table 3.
Figure 3. (a) NDVI values for study area in 2003, (b) NDVI value for study area in 2018

Table 2. The highest and lowest values of NDVI for two periods in the study

| Years       | High  | Low   |
|-------------|-------|-------|
| 2003/3/22   | 0.693 | -0.714|
| 2018/3/18   | 0.509 | -0.22 |

Figure 4. (a) Unsupervised Classification for NDVI image in 2003, (b) Unsupervised Classification for NDVI image in 2018

Table 3. Areas of vegetation cover extracted from NDVI in (Km²)

| Date of image | Area of vegetation cover in (Km²) |
|--------------|----------------------------------|
| 2003/3/22    | 2674.1                           |
| 2018/3/18    | 2334.7                           |
The change in vegetation cover is linked to the change in land surface temperature from the thermal band of satellite images to determine the effect of vegetation cover degradation on surface temperature as shown in figure 5.

Figure 5. (a) land surface temperature for the study area in 2003, (b) land surface temperature for the study area in 2018

The process of degradation of vegetation is a part of the various degradation processes experienced by natural ecosystems, degradation of vegetation is often treated as a part of land degradation processes. Degradation of vegetation is defined as a natural change in the natural plant system and decreasing its density which leaves its impact on the overall economic and social activities of humans. The causes of the deterioration are related to human beings and their practices, misuse of land, poor planning, and also to the natural and climatic changes such as low rainfall, high temperatures and increased salinity. In addition, factors like migration and the decline of agricultural labor, followed by a decline in cultivated areas, as well as the destruction of economic activities, especially the agricultural activity, cause deterioration. Depending on the digital data obtained from the analysis of satellite images for plant coverings in the study area and through the field survey, it has been observed from Table 2 and Figure 3 that the values of NDVI were high in 2003 and they are ranged from (-0.714 - 0.693). This indicates a high vegetal cover in that year, while its value was decreased to (-0.22 - 0.509) in 2018 pointing out to the significant deterioration of vegetation cover in 15 years. From Table 3 and Figure 4, the area of vegetation cover was 2674.1 Km² in 2003 then decreased to 2334.7 Km² in 2018. This indicates a decrease in the area of 339.4 Km² during 15 years. Figure 5 shows that the land surface temperature increased from (10.93-36.26) in 2003 to (22.62-50.29) in 2018. all this at the expense of converting the green, open and agricultural areas to residential, commercial and industrial uses, as well as making a large number of random settlements that appeared in Baghdad after 2003. The factors that have an effect on degradation of vegetation in the study area are: the majority of the natural plants are desert plants such as herbs and spiny plants, especially in the western
parts, and decreased soil fertility and thus loss of sufficient organic nutrients for the growth of good plant species in the study area. The prevalence of the problem of wind erosion in the study area, especially in the dry years, has contributed significantly to the decrease in vegetation cover and its dispersion, leaving the land barren without any plant life. The natural vegetation prevailing in the study area is being reduced by overgrazing, log harvesting and other human practices. As a result of the climatic conditions characterized by the study area in terms of high temperatures and low annual rainfall, the density of natural plants decreased and many plant species were exposed to extinction. There are scattered areas in the study area where the vegetation coverage decreased significantly and was confined to small areas of herbs and desert plants.

4. Conclusions

The results of the study showed that the use of satellite images in studying the state of changes in vegetation cover gives a clear impression in reaching the real results through data derived from satellite images. The values of NDVI were high in 2003 and they are ranged from (-0.714 - 0.693); this indicates a high vegetal cover, while its value was decreased to (-0.22 - 0.509) in 2018 pointing out to the significant deterioration of vegetation cover in 15 years. The area of vegetation cover was 2674.1 Km² in 2003 then decreased to 2334.7 Km² in 2018, this indicates a decrease in area of 339.4 Km² during 15 years. The land surface temperature increased from (10.93-36.26) in 2003 to (22.62-50.29) in 2018, all this at the expense of changing the green, open and agricultural areas to residential, commercial and industrial uses, as well as the large number of random settlements that appeared in Baghdad after 2003. The arid areas recorded the highest surface temperatures. It was (3-5) °C more than the green areas. There is an inverse relationship between the NDVI index and the land surface temperatures where the vegetation areas have the potential to reduce the thermal variation.

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