Research Article

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Seasonal normalized difference vegetation index responses to air temperature and precipitation in Baghdad

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Abstract: The spatial distribution of urban vegetation cover is strongly related to climatological conditions, which play a vital role in urban cooling via shading and reducing ground surface temperature and effective strategy in mitigation urban heat island. Based on the Landsat satellite images, the quantitative normalized difference vegetation index (NDVI) was spatially mapped at two times for each year during 2008, 2013, 2019 in Baghdad. The NDVI values ranged from -1 to $+1$ with considering values larger than 0.2 indicate the dense healthy vegetation. In this study, the fractional areas of NDVI >0.2 were computed with their percentage. The responses of the NDVI during the growing seasons to two climate indices (i.e., air temperature and precipitation) were investigated. These climatic data obtained from the Iraqi Meteorological Organization and Seismology for the aforementioned years were used to explore the potential correlations between seasonal NDVI and above climate variables. The result shows that NDVI-derived vegetation growth patterns were highly correlated with their recording during the current growth seasons.

Keywords: seasonal NDVI, air temperature, precipitation, correlation analysis, Baghdad

1 Introduction

The importance of urban vegetation (e.g., trees, grassland, green parks, and forests) in megacities is not only considered as the most effective strategy for urban cooling and

mitigate the urban heat island (Colunga et al. 2015) but also has a large impact on the quality of life in cities (Shah-mohamadi et al. 2011). It can reduce the land surface temperature through shading and modifying evapotranspiration, albedo and CO_2 sequestration (Rasool 1993).

Climatic conditions, human activities and socio-economic, political and environmental factors are directly and indirectly influenced the vegetation cover status. In this study, dynamic changes in vegetation cover in Baghdad and its relationship with climatic conditions, air temperature and precipitation, in particular, are investigated. They are main factors and mostly used to understanding climatic conditions because of their direct influences on soil moisture and hence the vegetation growth status (Wang et al. 2003). The study of climate indices is important for the city, because it is characterized with extreme events, especially in summer, when the highest air temperature reaches 50°C and no rain fall is observed from June to October with low air humidity. Unless mechanical irrigation was used, the vegetation cover would have damaged. In contrast, in winter, lowest temperature that sometimes drops to less than 0°C associated with limited rains can also lead to cease the vegetation growth. Rainfall in Baghdad generally occurs in January, February, April and May, so vegetation cover starts to grow from March to July and from September to November. These extreme climate patterns provide a broad area of investigation about the climate behavior and its impacts on the status of vegetation. Variations in climatic factors often lead to variations in vegetation cover for a given site, which are mostly carried out using normalized difference vegetation index (NDVI).

Many overview articles have been published investigating the variations in NDVI and their relationship with temperature and precipitation (e.g., Wang et al. 2003; Chu et al. 2007; Chuai et al. 2013; Hussein et al. 2017; Daham et al. 2018; Huang et al. 2019). They have mostly used the Advanced Very High Resolution Radiometer on board National Oceanic and Atmospheric Administration Satellite resolution with 1.1 km , but in this study, NDVI was derived from Landsat remote sensed imageries with a

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resolution $30\text{ m} \times 30\text{ m}$. High-resolution data can describe the vegetation coverage characteristics in a given area, but at the same time increase the difficulty of data collection and processing (Singh and Kumer 2017). The selection of the fine resolution will help to not only increase the accurate description of the field features but also improve the efficiency of agriculture and hydrological models, which impacts the outputs with the better conclusions and aid in making decisions by managers and planner in maintaining the vegetation cover in any region. The objectives of this article are as follows: (1) to analyze the spatial distribution of NDVI for three years: 2008, 2013 and 2019; (2) to investigate seasonal variations of air temperature and precipitation; and (3) to compare correlations between NDVI and temperature as well as NDVI and precipitation.

2 Study area and data

This study was conducted in Amanat Baghdad located in the province of Baghdad, which is the capital governorate city of Iraq (see Figure 1), including metropolitan area. It extends from $33^{\circ} 12' \text{ N}$ to $33^{\circ} 29' \text{ N}$ and from $44^{\circ} 10' \text{ E}$ to $44^{\circ} 36' \text{ E}$ with an area of 894.3 km^2 . The average elevation is approximately 34 m above the mean sea level. Baghdad lies along both banks of Tigris river, so has two residential parts called Rasafa (Eastern part) and Karkh (Western part). According to 2019 statistics, population census of Baghdad was over 7 million, and the population density was high in Rasafa side. The surface of Baghdad city comprises mostly low-rise houses (1–3 floors), medium-rise buildings up to 20 floors, green parks, forests, small water bodies, formal offices and hotels. Forests are mostly located at the north and south of the city, which comprised mostly date palms as native species. The terrain of Baghdad is flat and low-lying land, so Baghdad possesses dry climate with hot summer and damp winter and is classified as a semiarid zone (Roth 2007).

Two different types of data for only three years 2008, 2013 and 2019 are used in this study: (1) six satellite Landsat images, two images for different dates of each year, were downloaded from the USGS Earth Explorer website. These images were acquired from Landsat-5 Thematic Mapper (TM) for 2008 with Path 168 and Landsat-8 Operation Land Imager (OLI) for 2013 and 2019 with Paths 169. All images were in the Universal Transverse Mercator projection system, zone 38 with the World Geodetic System 1984, row 37, and cloud cover less 0.6%. Other features such as acquisition date, sun elevation and their times are presented in Table 1.

(2) Monthly mean air temperature and precipitation were obtained from Baghdad station belonging to Iraqi Meteorological Organization and Seismology.

3 Methodology

The most commonly used measure of vegetation cover is NDVI, which is based on difference in pigments absorption/reflection features of red (RED) and near-infrared (NIR) light. It was first proposed by Rouse et al. (1974) and has been widely used by researchers to estimate green biomass, leaf area index, crop productivity and patterns of vegetation cover change (Wang et al. 2003). The internal mesophyll structure of healthy green leaves reflect RED, while leaf chlorophyll and other pigments absorb a large proportion of NIR (Sellers et al. 1992; Mavi and Tupper 2004). NDVI is calculated by the following formula (Roerink et al. 2003):

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \quad (1)$$

where NIR stands for Band 4 in Landsat-5 TM and Band 5 for Landsat-8 OLI and RED represents Band 3 in Landsat-5 TM and Band 4 in Landsat-8 OLI.

The values of NDVI range between -1 and $+1$. Increasing positive NDVI values indicate the dense vegetation, and close to zero or decreasing negative values indicate the non-vegetation surface such as water and bare land (Schnur et al. 2010; Chuai et al. 2013). Before calculating the NDVI, the original digital number (DN) data were converted into top of atmosphere planetary reflectance (ρ_λ) by using gain and offset values taken from Metadata file of the images (Chander and Markham 2003), using the following equation:

$$\rho_\lambda = \frac{M_p \times Q_{\text{cal}} + A_p}{\sin(\theta)} \quad (2)$$

where M_p is the band-specific multiplicative rescaling factor, A_p is the band-specific additive rescaling factor, Q_{cal} is the quantized and calibrated standard product pixel values ($=\text{DN}$) and θ is the local sun elevation angle in degrees. The calculations of atmospheric correction, NDVI and reclassifying were done using ArcGIS 10.4 software. The overall accuracies of vegetated areas were spatially located by selecting many controls points and established them with the ground truth using Google Earth and field work.

To examine the relation between NDVI response and climatic variables, a simple linear regression analysis with the following equation was applied to explore their relations with a few data points of only three years.

Figure 1: Maps of (a) Iraq and (b) the study area of Amanat Baghdad.

$$Y = \alpha + \beta \times X \quad (3)$$

where Y represents the dependent variable (NDVI), α is the intercept, β is the slope and X is the independent variable (air temperature or precipitation) over the studied period. The constants α and β were derived from the values of variables X and Y using the Origin software (version 9.3). In addition, Pearson's linear correlation coefficient (r) was also computed for each relation.

4 Results and discussion

4.1 Spatial distribution of seasonal NDVI variations

Based on equations (1) and (2), NDVIs were extracted for all months (Table 2). April to July associated with high

NDVI values represent the best growing months while December to March are the least growing. NDVI values were classified into major two categories: vegetation with positive NDVI values >0.19 and nonvegetation for NDVI values <0.19 (Xie et al. 2018; Hashim et al. 2019). Figure 2a–f shows the spatial distribution of positive NDVI for the studied months and years, March and June 2008, December and July, 2013 and January and July 2019. In general, the vegetation cover was concentrated on the outskirts of Baghdad city, especially toward north and south, where forests were dominant. Also the lowest vegetation cover amounts are found in 2008 and then increased in 2013 and 2019. This is attributed to different climatic conditions associated with these years, which is shown in the following section. There was a large patch of nonvegetation in the eastern part of the city (Rasafa part), which reveals that it has many poor settlement districts and high population density, bare soil and low NDVI values.

Table 1: Acquisition date, sun elevation and time for satellite images analyzed in this study

Satellite/sensor	Year	First image			Second image		
		Date	Sun elevation (°)	Time (GMT)	Date	Sun elevation (°)	Time (GMT)
Landsat-5 TM	2008	6/3	43.74	10.23	26/6	65.6	10.21
Landsat-8 OLI	2013	24/12	29.95	10.41	1/7	68.21	10.41
Landsat-8 OLI	2019	2/7	67.76	10.39	7/1	30.22	10.39

Table 2: NDVI values, vegetation area, their differences and percentages for 2008, 2013 and 2019

Years	Average NDVI				NDVI area (km ²)			
	Winter	Summer	Difference	NDVI	Winter	Summer	Difference	Ratio (%)
2008	0.46	0.25	−0.21	0.36	108.9	126.3	17.4	1.9
2013	0.45	0.51	+0.06	0.48	267.1	307.8	40.7	4.6
2019	0.44	0.51	+0.07	0.47	224.5	263.8	39.3	4.4

The variations in NDVI with larger than 0.2 between the months at all years are evident, and the associated peak values of greenery also vary. The detailed information on vegetated areas, NDVI values and their differences are summarized in Table 2. In each year, NDVI values during winter represented by months (December or January) decreased and then increased reaching the peak during summer months (June or July). This change can clearly reflect the vegetation phenology responding to seasonal atmospheric forcing. In both 2013 and 2019, there was a greenness exceeding +0.06 and +0.07 in NDVI from winter to summer months, while there was a large decrease with −0.21 in 2008 as presented in Table 2. This is also associated with an increase in the vegetated area of 40.7 km² in 2013 and 2019 and 17.4 km² in 2008. Decreasing in NDVI and the little increasing in the vegetated area in 2008 may be due to severe climatic conditions and unstable political system occurring after 2003. Finally, the average NDVI value of each year was calculated from the minimum and maximum NDVIs.

4.2 Seasonal variations of temperature and precipitation

Both air temperature and precipitation (mostly rainfall) are the most important climatic variables that play a significant rate in the vegetation growth and its productivity. Seasonal mean temperature and precipitation data were obtained by taking the means of their monthly data for each year of studied period as follows: winter, December–February; spring, March–May; summer, June–August and autumn, September–November. Meanwhile, seasonal accumulative sums of precipitation for these months were also determined. These seasonal means and accumulations are displayed in Figure 3a and b, respectively, which represent the annual cycles for both variables. During summer months, there was never any precipitation types

(see Figure 3b), which reflect, in addition to the maximum number of daytime hours, in increasing air temperature to 35 °C (Figure 3a). The highest temperature, certainly, enhances the suppression of the vegetation activity in summer. However, across all years, seasonal mean temperatures have uniform variations during any time in the year, while seasonal precipitation showed strong variations especially in spring. Also, across all seasons, the lowest temperature was recorded in winter especially in 2008 with ~10 °C, moderate temperature was recorded in both spring and autumn with ~23 °C as shown in Figure 3a. Most frequent precipitation in Baghdad occurs in winter produced by external pressure systems passing over the city coming from Mediterranean and northern Africa. Therefore, growing season length usually reaches maximum activity in spring and summer even if irrigation by runoff or soil moisture is available. In this case, seasonal temperature and precipitation data in spring are more convenient to study their correlations with annual NDVI values, which is discussed in the next section.

4.3 Relationships between NDVI and climate variables

4.3.1 NDVI versus seasonal temperature

Figure 4a displays the results of mean NDVI ($\overline{\text{NDVI}}$) and seasonal mean air temperature of spring months for three years 2008, 2013 and 2019. It can be noted that $\overline{\text{NDVI}}$ data decrease gradually with the increasing seasonal means of temperature in springs. The solid line is plotted to represent the best fitting using equation (3). The values of empirical constants α and β are derived from these variables, which are presented in Table 3. The negative value of the slope ($\beta = -0.04$) reflects the inversely correlation between the seasonal means of both mean NDVI and air temperature with coefficient of −0.896.

Figure 2: Maps of NDVI distribution in (a) March and (b) June 2008; (c) December and (d) July 2013; (e) January and (f) July 2019.

Figure 3: Seasonal variations for (a) temperature and (b) precipitation of 2008, 2013 and 2019.

Table 3: Values of constants of equation (3) with correlation coefficient (r)

Relation	α	β	r
NDVI versus temperature	1.4	-0.04	0.896
NDVI versus precipitation	0.36	0.002	0.97

4.3.2 NDVI versus precipitation

We studied the relation between $\overline{\text{NDVI}}$ and precipitation collected during spring months for years 2008, 2013 and

2019. These results are presented in Figure 4b, which shows the strong linear correlation between them with coefficient 0.97. The best line is also drawn among these data points using equation (3) as shown in Figure 4b, and its constants α and β are reported in Table 3. The positive value of the slope ($\beta = 0.002$) reflects the dependence of $\overline{\text{NDVI}}$ on the precipitation. The less precipitation (1.7 mm) is associated with the increasing seasonal temperature (25.2 °C), while great precipitation associated with moderate seasonal temperature (23.4 °C) produces high value of $\overline{\text{NDVI}}$.

Figure 4: Variation of $\overline{\text{NDVI}}$ with (a) seasonal mean temperature and (b) precipitation.

5 Conclusion

The combinations of NDVI based on remotely sensed imageries and climatic records such as air temperature and precipitation were analyzed to explore their correlations across a semiarid environment like Baghdad. Based on the monthly base of these data in the first half of the years 2008, 2013 and 2019, NDVI, temperature, and precipitation variations are studied to investigate the relationships between NDVI and climate characteristics. Although precipitation often occurred in winter, there is a limited vegetation growth and reaches the late spring because of the dropping in air temperature.

The temporal NDVI analysis found to be more sensitive to natural events such as drought and human activities, where NDVI reduces to its lowest value in the summer of 2008 and its peak in 2013 and 2019 for the same season. This is associated with an increase in the area of NDVI covers about 40 km² with a ratio of 4%. With taking the seasonal averages for all NDVI values, temperature and precipitation, we found that there are significant relations between them, with both negative and positive correlations. The results show that NDVI is negatively correlated with temperature with a coefficient of -0.896 and is positively correlated with precipitation with a coefficient of 0.97 . This shows that the air temperature is a primary driver in the vegetation growth in Baghdad, and the highest temperature can also lead to adverse effects. However, we realize that more records and much research might be needed to further understand the relationship among NDVI, temperature and precipitation in semiarid environments.

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Conflict of interest: The authors declare no conflict of interest.

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