Conference Paper

The Use of Remotely Sensed Data for Analysis of the Influence of the Urban Environment on the Seasonal Growth of Arboreal Vegetation

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Abstract

The aim of this study was the analysis of the peculiarities of the growth of oak and pine stands in the city of Ufa and its suburbs in the spring by using visual monitoring of the development of leaves of the crown, the Normalized Difference Vegetation Index (NDVI) and thermal satellite channels in the spectral range of 10.4–12.5 microns. Analysis of cloudless Sentinel-2, Landsat 7 and Landsat 8 images and the ASTER Global Digital Elevation Model Version 2 (GDEM V2) was used. It was found that the oak and pine stands had faster seasonal growth within the urban area than outside the city. It was impossible to fully capture the average daily differences between various areas, including the temperature differences between day-time and night-time temperatures, through the thermal satellite channels. Yet, some temperature differences between various areas can be estimated by using thermal satellite channels.

Keywords: city, remote sensing, temperature, forest, NDVI, Sentinel-2, Landsat TM/ETM+

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1. Introduction

Various aspects of the urban environment explored by Earth Remote Sensing have been a concern for many studies, as reviewed by Qihao Weng [1]. Impervious surfaces like roadways, driveways, sidewalks, parking lots, house-tops, etc., were analysed in most studies. A number of studies demonstrated that the temperature of impervious surfaces is higher than the temperature of vegetation [2, 3]; the enlargement of green plantations may lower the trend for the temperature of the urban environment to increase [4]. One of the important components of urban green areas are public squares and parks, which are exposed to less thermal pollution than small green areas bordering roadways and sidewalks. Increasing the air and ground vegetation temperature in a city may influence seasonal rhythms of the development of urban vegetation. Insufficient research has been conducted on the effect of temperature conditions in cities on the development of arboreal vegetation because of the difficulty of finding forest plantations that are relatively homogeneous in their arboreal structure and large enough to be analysed through thermal satellite channels. The most problematic issue is that it has appeared difficult (and sometime impossible) to obtain satellite imagery with high enough spatial and temporal resolutions to retrieve temperature data [2, 5, 6]. The low resolution of images results in an effect of temperature mixing, in which a pixel of a satellite-derived land surface temperature image is larger than the thermal elements [6].

Lime and oak forests were the main type of arboreal vegetation the interfluve of the Ufa and Belaya rivers; nowadays, the area is occupied by the urban settings of the city of Ufa. Remnants of the forests are preserved in park areas of Ufa. The planting of pines is used for reforestation. The aim of this study is an analysis of the peculiarities of growing oak and pine stands in Ufa and its suburbs in the spring by using visual monitoring of the development of leaves of the crown, the Normalized Difference Vegetation Index (NDVI) and the thermal satellite channels of Landsat 7 and Landsat 8.

2. Methods

Several homogeneous forest areas were identified as Scientific Permanent Plots (SPP). An SPP with a predominance of *Quercus robur* (Q1) was located outside the city next to village of Timashevo, Q2 was located in Ufa in Kalinin Park and Q3 was located in Ufa next to city clinical hospital №18. SPPs with the predominance of middle-aged *Pinus sylvestris* were set up next to village of Timashevo (P1) and in Kalinin Park (P2). Detailed information about the SPPs is presented in Table 1.

Some peculiarities in the seasonal development of woody and shrubby vegetation were registered in the SPPs from the end of April (snow cover melted totally) to mid-June (completed frondescence of crowns) at 5 to 7 day intervals.

The Normalized Difference Vegetation Index (NDVI) was used to analyse the seasonal growth of vegetation as the NDVI reflex efficiency of photosynthesis per unit

Table 1: Description of Scientific Permanent Plots (SPP) with a predominance of *Quercus robur* and *Pinus sylvestris* in the city of Ufa and its suburbs.

SPP	GPS coordinates of the centre of a SPP	Size, ha	Altitude, m	Slope exposure	Slope angle	Relative proportions of tree species	Tree crown cover
Q1	54°49′0″ N, 56°8′34″ E	2.45	149	194° (SSW)	3°	8Q1A1U	*35** 60
Q2	54°47′56″ N, 56°2′52″ E	0.73	130	212° (SSW)	2°	8Q2T	*45* 40
Q3	54°47′8″ N, 56°1′19″ E	0.68	150	184° (S)	26°	8Q2A	*40* 60
P1	54°49′44″ N, 56°8′39″ E	1.23	138	287° (WNW)	3°	10P+T	*50* 25
P2	54°47′55″ N, 56°2′39″ E	0.7	137	147° (SSE)	1°	10P	*50* 50

Source: Authors' own work.

Note: Q – *Quercus robur,* A – *Acer platanoides,* U – *Ulmus glabra,* T – *Tilia cordata,* P – *Pinus sylvestris*; * – above is the percentage cover of tree crowns, below is the percentage cover of young trees and growth of seedlings.

area and changes depending on the stage of the seasonal development of vegetation. The NDVI was derived from analysing cloudless Sentinel-2 images for the period between 11 April and 30 July 2017: the processing started with radiometric and atmospheric correction to the images [7]. Morphometric analysis of the digital elevation models ASTER GDEM V2 was used to extract altitude and descent (exposure and gradient) in the SPPs. The temperature in SPPs was extracted from the thermal satellite channels of Landsat 7 and Landsat 8 in the spectral range of 10.4–12.5 microns. Thermal Infrared Sensor data were converted from spectral radiance to brightness temperature, which is the effective temperature viewed by the satellite [8]. All the calculations were carried out by QGIS with GRASS GIS Integration; the Zonal Statistics Plugin was used to calculate the mean value of NDVI, temperature, altitude and other values for each SPP.

3. Results

The evaluation of the temperature profile through thermal satellite channels may be reasonably accurate under cloudless conditions; according to an earlier study, there was a correlation coefficient of 0.9 between the temperature of the surface derived from satellite channels and the temperature obtained from temperature sensors [9]. Snow cover results in temperature differences between open areas and forests. In

2017, well warmed up surfaces such as roadways, sidewalks and house tops had been free of snow cover since 11 April, before arboreal vegetation started growing. As a result, at 12 noon local time (when the Landsat satellites pass), the temperatures in SPPs in the city (Q2, Q3, P2) were 6 to 8°C lower than temperatures in open areas adjoined to the forest stands (Table 2). At that time, there was snow on the open areas adjoined to the forests: therefore, the temperature of the ground vegetation in open areas adjoined to the village Timashevo was 1°C lower than in the forest SPPs Q1 and P1. Two weeks later, on 26 April, the temperatures in all the SPPs were 5 to 10°C lower than the temperature in open areas. The only exception was Q3, where the temperature was 1°C higher than in the other locations. The probable reason was that the slope of the southern exposure warmed up more quickly after the sharp temperature drop at night on this date. Further temperatures in all SPPs were 2 to 8°C lower than in open areas. The same differences in temperature profiles were recorded in other cities located in biomes with a predominance of broad-leaved and mixed forests of the temperate zone [10]. Therefore, forests serve as a thermal buffer in which the temperature is slightly higher during the snow period and lower after the snow melts than in open areas.

The influence of increased impervious surface temperature on forest stands in a city should gradually come to nothing with increasing distance from the forest edge. That is why the temperature in the pine stands in the city (P2), located 130 m from the forest edge, was 1.5°C higher than in the SPP in the suburb (P1) on 11 April (Table 2). On that day, the temperatures in the oak stands in the city Q2 and Q3, located 230 m and 330 m, respectively, from the forest edge, did not differ significantly from the temperature in Q1 located in the suburb. After the start of arboreal vegetation growth on 26vApril, the temperature in all SPPs differed insignificantly. Q3 was an exception because its temperature was 7 to 7.5°C higher; this was due to its location on a steep slope of southern exposure (Table 1). The advent of warm weather led the temperatures in all the SPPs to become similar.

The seasonal growth of the warmth-requiring species *Q. robur* in Ufa and its suburbs is slower than the growth of other forest-forming arboreal species. At the beginning of arboreal vegetation growth, the highest temperature was recorded in Q3; this resulted in the quicker seasonal growth of oaks in Q3 in comparison with Q1 and Q2 (Figure 1(A)). The slowest growth of leaves in oaks was recorded in Q1 outside the city. According to visual observations, the completed crown foliage was recorded on 26 May in the city. At the same time, the foliage did not exceed 50% of the summer foliage in the suburb.

Completed tree crown foliage in Q1 was recorded two weeks later than completed foliage in the SPPs in the city (Figure 1(A)).

Table 2: Peculiarities of the temperature profiles in the SPPs with a predominance of *Quercus robur* and *Pinus sylvestris* in Ufa and its suburbs.

Dates of satellite images	Temperature in forest SSPs, °C					Temperature in open areas* adjoined to forest SSPs, °C		
	Q1	Q2	Q3	P1	P2	O1	O2	O3
11.04.2017	2.8	3.0	3.7	2.2	3.6	1.2	9.9	11.8
26.04.2017	1.6	1.3	9.0	2.0	1.6	6.7	8.0	11.8
20.05.2017	21.2	19.6	19.4	20.9	19.3	24.0	25.4	27.4
13.06.2017	19.0	19.3	19.1	19.1	19.0	21.1	26.2	27.1

Source: Authors' own work.

Note: Details about SSPs Q1, Q2, Q3, P1, P2 are in Table 1; * – open areas adjoined to forests: O1 – adjoined Q1 and P1, O2 – adjoined Q2 and P2, O3 – adjoined Q3.

Pine needles continue photosynthetic activity all year round. However, the activity is relatively low after snow has melted if the temperatures are still low. In pine stands, the NDVI was 0.27 to 0.28 on 26 April; it was roughly equal to the NDVI of oak stands at the beginning of seasonal growth (Figure 1). In general, pine stands had slower seasonal growth than oak stands. A graph of pine stand NDVI dynamics did not display pronounced inflection between spring and summer growth, though such an inflection is typical for broad-leaved arboreal species. In the summer, the photosynthetic activity evaluated on the NDVI was lower in pine stands than in oak stands. Differences in seasonal growth between pine stands in the city and outside it were less than the differences between oak stands in different locations (Figure 1(B)).

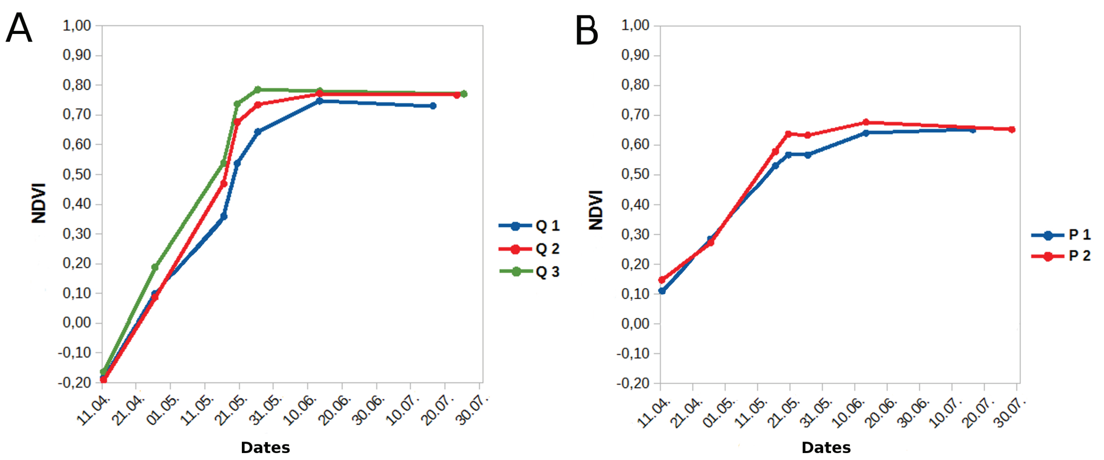

Figure 1: Seasonal NDVI dynamics in SPPs with a predominance of *Quercus robur* (A) and *Pinus sylvestris* (B) in Ufa and its suburbs (Details about SSPs Q1, Q2, Q3, P1, P2 are in Table 1). Source: Authors' own work.

4. Conclusion

To summarize, the seasonal growth of oak and pine in a city are quicker than in suburbs. The temperature differences evaluated through thermal satellite channels reflect temperature profiles at 12 noon local time. Consequently, the data do not represent the complete picture of average daily temperatures, including differences between daytime and night-time temperatures as well as the temperature profile in the period of maximum soil warm-up, the afternoon. However, the data allow for the identification of temperature patterns in various areas. It is impossible to evaluate the patterns without thermal sensors, but setting up sensors is problematic in a city.

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