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Evaluation and Correlation of Sentinel-2 NDVI and NDMI in Kyiv (2017–2021)

Oleksandra Strashok[1,2*], Monika Ziemiańska[1], Vitalii Strashok[3]

[1] Wroclaw University of Environmental and Life Sciences, 55 Grunwaldzka Str., 50-357 Wroclaw, Poland

[2] Department of Landscape Architecture and Phytodesign, National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony st. 15, Kyiv 03041, Ukraine

[3] Scientific and Research Department, National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony st. 15, Kyiv 03041, Ukraine

* Corresponding author's e-mail: o.strashok@upwr.edu.pl

ABSTRACT

For the last 20 years researchers have tried to create new approaches of managing urban ecosystem by using remote sensing methods. The authors estimated the normalized vegetation index (NDVI) and moisture index (NDMI) indices of Kyiv and propose an approach which can be used for estimation vegetation of other cities. The aim of the study was to assess the indicators of NDVI and NDMI in Kyiv for the last 5 years. The authors consider the NDVI index as an important ecostabilizing component of the urban ecosystem, as well as an indicator of the well-being citizens in a modern city. The study used space images of the Sentinel-2 satellite system with resolution of 10×10 m and 10×20 m. The images were decrypted using the Sentinel Hub platform which updates the database daily. The paper presents the results of correlation analysis using Statistica-6.0 software and demonstrate the close relationship ($r = 0.73$, $r^2 = 0.55$) between NDVI and NDMI. Thus, the statistical results of the study confirm a strong correlation between photosynthetic activity of plants and indicators of their water content by satellite imagery which allows using modern satellite technologies to assess the functional state of the urban vegetation. The changes in the length of active vegetative growth period were identified by NDVI and NDMI. The results of the research expand the directions of the methods of monitoring the condition of the urban vegetation cover in the aspect of applied landscape research.

Keywords: plants, space images, urban vegetation, urban ecosystem.

INTRODUCTION

The city is a dynamic system with a complex of heterogeneous landscape. According to the data, about 50% of the world's population currently lives in urban areas, and by 2050 it is projected that 66% will live here [Zaitunah A., 2021]. The urban landscape is considered the most complex on the earth's surface [Guha, 2020]. The vegetation of urban landscapes serves as an eco-stabilizing element in the city due to a wide range of ecosystem services [Wu, 2010; Robinson, 2012; Rozova, 2020]. Scientists Zhang et al. [2020] note that in order to provide ecosystem services in the urban areas, it is necessary to take into account vegetation in urban planning. Today, researchers widely use remote sensing methods to monitor and assess the environment, forestry and agriculture [Nuthammachot et al., 2018; Carranza et al., 2019; Delgado and Gao, 2020]. In the past decades, a large number of different indices have appeared for estimating the earth's surface based on modern technologies and extracting information from different satellite systems. For studying the Earth's vegetation, images and thematic maps by Landsat, MODIS, SPOT, ASTER, AVHRR, IKONOS, CBERS QuickBird, RapidEye, WorldView, LiDAR, Radar, Sentinel and ALOS PALSAR are often used [Isbaex and Coelho, 2021]. There are many electronic platforms that allow

processing free images from different satellites and evaluating various metrics. They all have different spatial, spectral, and temporal parameters [Isbaex and Coelho, 2021]. The vegetation indices are mathematical functions formed from different quantities of spectral bands [Ku and Popescu, 2019].

NDVI is one of the most popular and readily available vegetation indices that can be obtained from remote sensing data [James et al., 2015]. The index is used to assess the functional state of plants as well as its correlation with photosynthetic activity, humidity, vegetative and non-vegetative areas, etc. [Xue et Su, 2017; Koskinen et al., 2019]. In addition, NDVI is widely used by scientists in epidemiological studies [Gascon et al., 2016].

NDMI characterizes the water stress level in plants [Gao 1996]. This index is most commonly used to monitor drought stress and vegetation moisture content [Nasiłowska and Kubiak, 2016]. The NDMI indicators have a strong correlation with dry matter in leaves [Wang, 2011].

The study of vegetation as component of the urban system will allow controlling and modeling biophysical processes in the urban environment [Yu et al., 2004; Li et al., 2016]. The indices can be used in the design of urban green space development strategies to mitigate the effects of heat island [Shahfahad et al., 2022].

MATHERIALS AND METHODS

The purpose of the conducted research was to access the state of vegetation in Kyiv by the NDVI and NDMI indicators for 5 years. The authors also planned to find a pattern between the NDVI and NDMI indicators as the growth rate of plants is closely related to their moisture supply. The area of Kyiv (50° 27’ 0.0036’’ N and 30° 31’ 23.9988’’ E) is 836 km^2 and population approximately 2.9 mln [Statistical Publication 2022]. According to the Master plan of Kyiv (2020), green and recreational areas are 54.5%; therefore, a large part of the city is surrounded by green areas.

Kyiv has a temperate continental climate with cold winters and warm summers. The average temperatures are 8.0 °C (annual), -5.0 °C (January), +20.2 °C (July). The absolute minimum and maximum are -32.9 °C and +39.4 °C. The average duration of the frost-free period is 188 days. The average relative humidity for the year is 75%. The average annual rainfall is 641 mm, in some years it varies from 400 to 795 mm. During the active plant growing season, rainfall amounts to 350–400 mm. The highest rainfall occurs in May–July [Central Geophysical Observatory named after Boris Sreznevsky].

To determine the NDVI and NDMI, the Sentinel Hub platform with access to Sentinel-2 satellite images that updated daily was used. The archival images and data for 5 years were analyzed. Satellite images were selected with 0% cloud coverage. Sentinel-2 contains 13 bands with different spatial resolutions from 10 to 60 m and provides high-resolution multispectral data [Yokoya 2016] (Table 1). The authors received and analyzed 128 data of NDVI and NDMI indices. The Sentinel Hub platform was used for digital map processing.

NDVI was calculated by the formula and can range from -1 to 1, where negative values indicate water.

$$\mathrm{NDVI} = \mathrm{Index}(\mathrm{B8}, \mathrm{B4}) = \frac{\mathrm{B8} - \mathrm{B4}}{\mathrm{B8} + \mathrm{B4}} \qquad (1)$$

The index is calculated according to radiances or reflectance from a red channel around 0.66 μm and a near-IR channel around 0.86 μm [Gao, 1996].

The NDMI is a normalized difference moisture index with the near infrared (NIR) and the shortwave infrared (SWIR) bands to display moisture. Researchers use NDMI to monitor the changes in water content of leaves. The SWIR bands depend on the changes in the vegetation water content and the spongy mesophyll structure

Table 1. Specification of spectral bands for the Sentinel-2 sensor

Bands	Central wavelength (nm)	Resolution (m)
1	443	60
2	490	10
3	560	10
4	665	10
5	705	20
6	740	20
7	783	20
8	842	10
8b	865	20
9	945	60
10	1380	60
11	1610	20
12	2190	20

of plants canopies. The water content does not affect the NIR, but it depends on leaf internal structure and leaf dry matter content. NDMI was calculated by the formula and can range from -1 to 1. Negative values can indicate water stress.

$$\text{NDMI} = \frac{\text{B08} - \text{B11}}{\text{B08} + \text{B11}} \quad (2)$$

Statistica 6.0 software was used for statistical analysis and creation of a 3D Surface Plot.

RESULTS AND DISCUSSION

The results of the research show that the NDVI indicators gradually increase during the growing season of plants and gradually decrease with the onset of dormancy. Thus, the peak of the NDVI values can be observed in summer with total photosynthetic active radiation of deciduous and coniferous plants. The data from the space images of the research area show the heterogeneity of vegetation in the city due to the urban planning structure and development of central and peripheral areas of the city. The processes of urbanization in addition to man-made load are one of the decisive in the formation of vegetation in cities. Thus, it is possible to single out the greenest areas of the city of Kyiv according to NDVI indicators which are highlighted on the map by dark green color (Figure 1).

All plants consist of water which is vital necessary for normal growth and development. Since NDMI is used by scientists to determine the moisture content of plants, this index determines the basic physiological processes of plants, including the photosynthetic activity.

Digital map processing results show that Figure 1 is similar to Figure 2, because the area with higher NDVI coincide with research sites with higher NDMI values.

For a detailed analysis of the NDVI and NDMI indicators, the data were interpreted into graphical curves and distributed over the years (Figure 3). The graphs show the dynamics of changes in indicators depending on the season and the activation of growth processes in plants during the growing season. It is well-known that

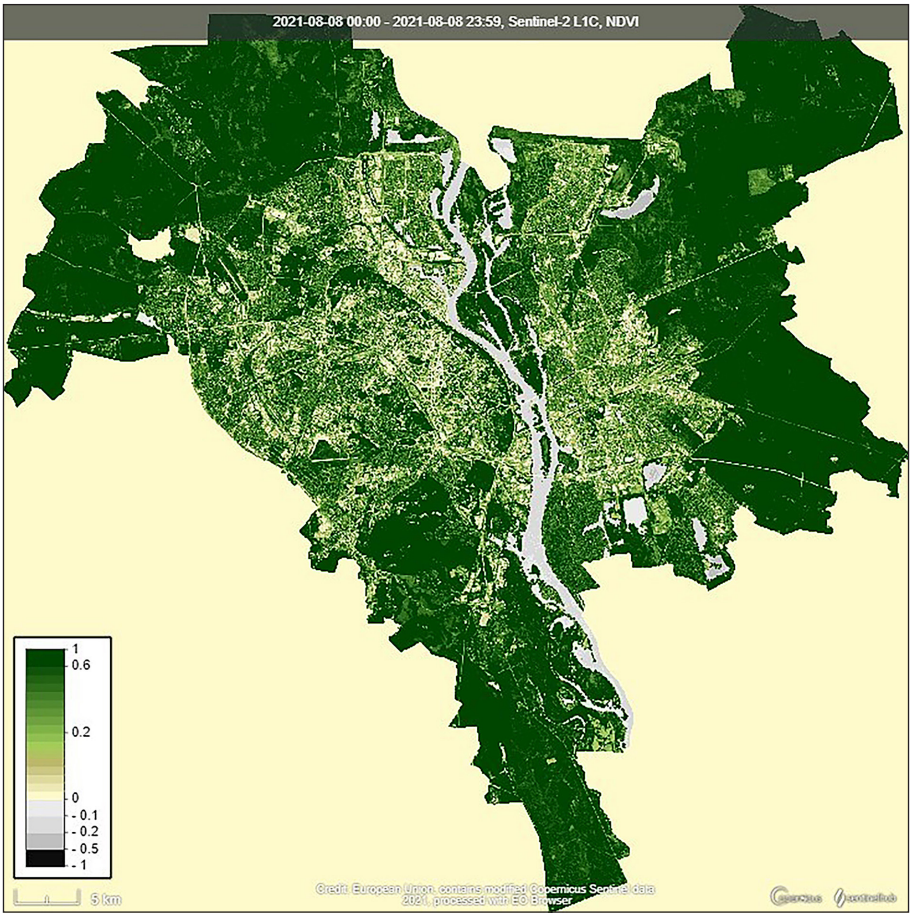

Figure 1. Map of NDVI in Kyiv (2021-08-08, Sentinel-2)

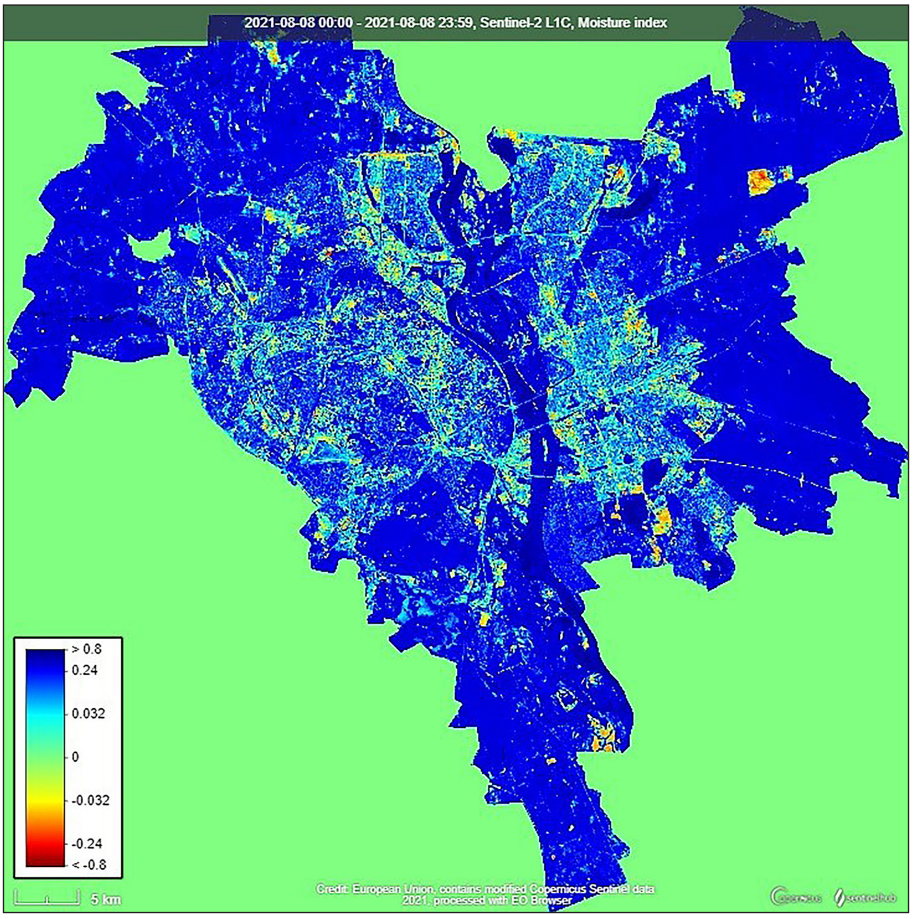

Figure 2. Map of Moisture Index in Kyiv (2021-08-08, Sentinel-2)

the growing season of plants depends on the climatic zone, which is characterized by its climatic conditions. Thus, different plants are characterized by different lengths of the growing season, but for the conditions of Kyiv, most plants begin to grow at a temperature of 5 °C in March–April depending on the temperature. It should be noted that the average annual temperatures for the last 10 years in Kyiv increased by 1.7 °C, which indicates climate change and variability of heat for plants [Strashok, 2022]. In authors' opinion, there is a high probability of changes in ecological optimums for plant species which will be accompanied by changes in the length of the growing season.

The data analysis of the research indicators allowed identifying the presence of dependence, to identify the nature of the relationship and its closeness. The closest relationship was found to be in the range of 0.41–0.52 NDVI and 0.18–0.24 NDMI, characterized by r = 0.7394 (Figure 4). Thus, the most informative periods were May–September.

The results of 3D surface analysis of correlation show a heterogeneous distribution of coefficients throughout the year (Figure 5). It was found that the most informative periods for assessing the functional state of vegetation in Kyiv were May–August 2017, May–August 2018, July–August 2019, July–September 2020, May–October 2021.

The results of statistical analysis indicate a time shift periods of photosynthetic activity of urban vegetation in Kyiv. Thus, in 2017–2019, the last month with strong correlation of the NDVI and NDMI indices was August, in 2020 was September and in 2021 was October. The obtained findings can be explained by climate changes and modification of ecological optimum for plants. At the beginning of the 21st century, Ukrainian scientists noted that the annual air temperature in Ukraine has increased by 0.8 °C over the past 20 years and continues to rise [Barabash, 2004; Adamenko, 2007]. It should be noted that NDVI and NDMI are dynamic indicators that depend on biotic and abiotic factors which are more vulnerable to urban ecosystems compared to other

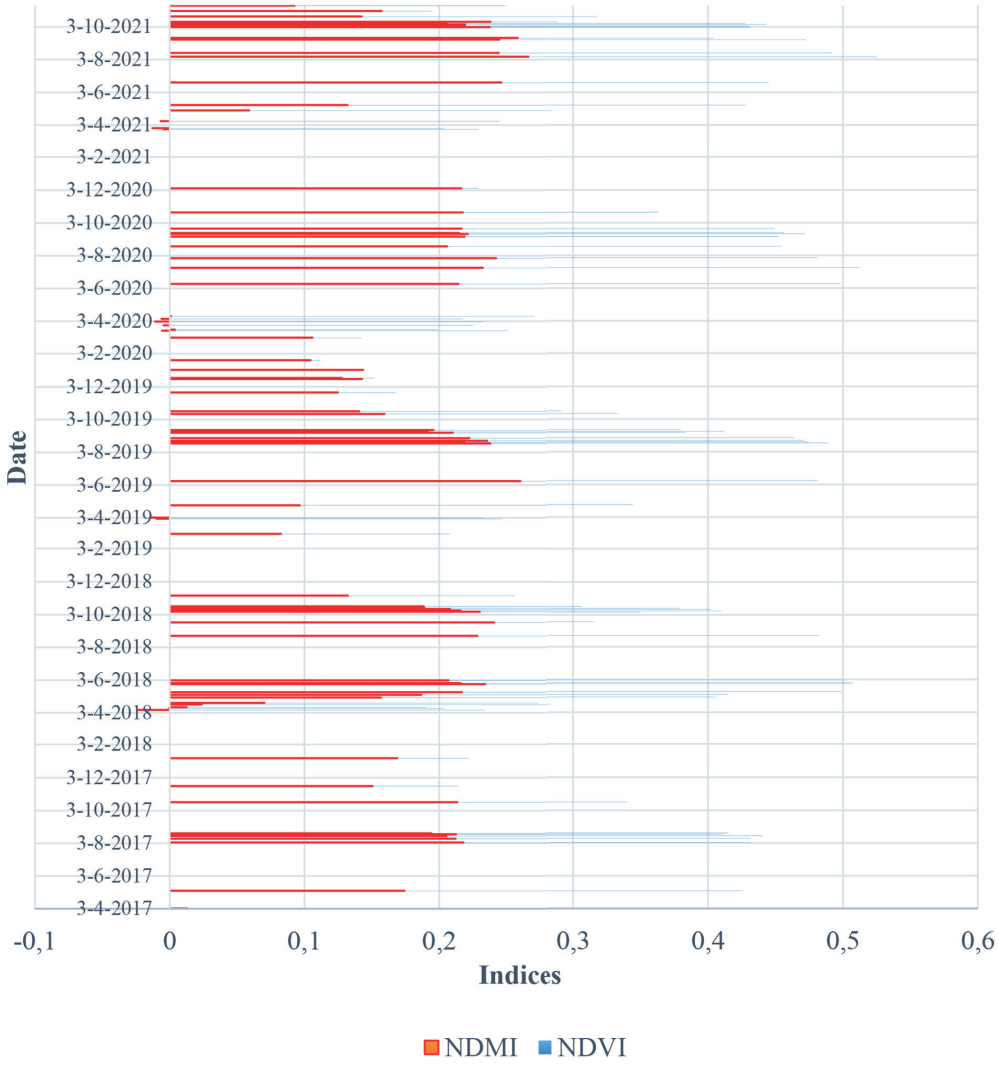

Figure 3. NDVI and Moisture index (NDMI) in Kyiv (2017–2021)

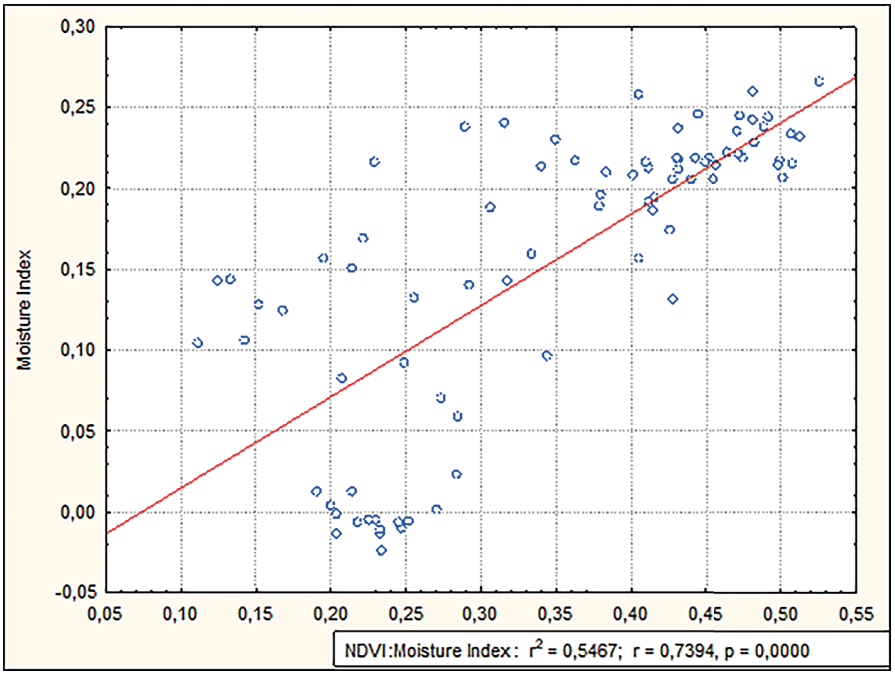

Figure 4. Correlation between NDMI and NDVI

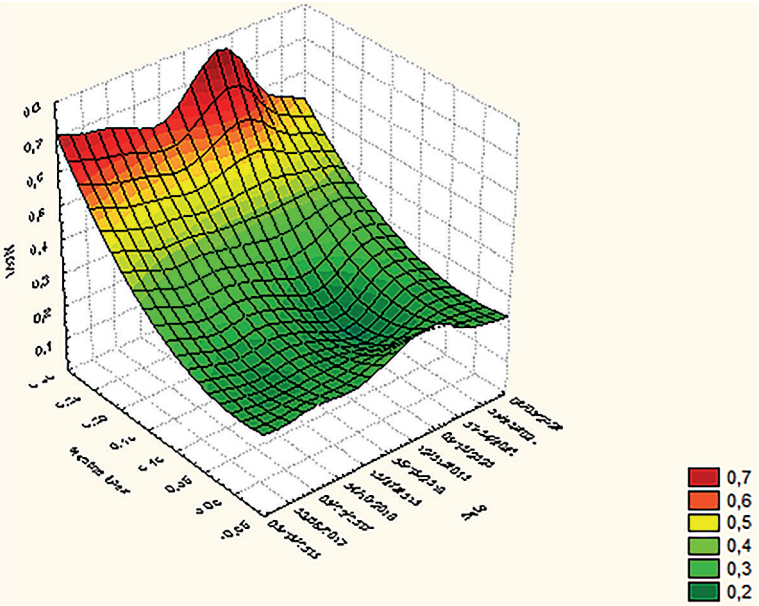

Figure 5. 3D Surface Plot of NDMI, NDVI and Date (Moisture Index=Distance Weighted Least Squares)

ecosystems. Researchers noted that temperatures have risen over time in Ukraine with the greatest variability during the winter season, but there is no tendency for precipitation [Wilson et al., 2021].

CONCLUSIONS

The NDVI and NDMI indices are dynamic indicators that characterize the functional state of the Earth's vegetation. The research results demonstrate that the most informative periods for the study of the NDVI and NDMI indices in Kyiv were different periods in different years: May–August in 2017 and 2018, July–September in 2019 and 2020, May–October in 2021. Some modification in time shift periods of photosynthetic activity of urban vegetation in Kyiv was found. The variability of the NDVI and NDMI activity in different years which is probably due to different amounts of active temperatures, but this issue needs further study. The results of the study indicate a close correlation between the NDVI and NDMI indices (r = 0.7394). The obtained research findings expand the directions of the methods of monitoring the condition of the vegetation cover in the aspect of applied landscape research.

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