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MAPPING THE DIMENSION OF SOIL SEALING IN CRAIOVA CITY (ROMANIA) USING GIS AND REMOTE SENSING TECHNIQUES

CARTAREA ETANȘĂRII SOLULUI ÎN CRAIOVA (ROMÂNIA) FOLOSIND TEHNICI GIS ȘI TELEDETECȚIE

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Abstract: The rapid growth of urban areas and the increase in sealed surfaces have significant implications for environmental management and urban planning. Monitoring and quantifying sealed surfaces are crucial for understanding urbanization processes and their impacts. This article deals with the issues of mapping the dimension of soil sealing in Craiova city, during the last two decades using GIS and remote sensing techniques. As the Normalized Difference Built-up Index (NDBI) has emerged as a valuable tool for assessing sealed surfaces and evaluating urban expansion, it was selected as preferred method selected to determine the dimension of soil sealing.

Key-words: *built-up area, soil sealing, NDBI, Craiova.*
Cuvinte cheie: *zonă construită, suprafață de etanșare, NDBI, Craiova.*

1. INTRODUCTION

The rapid urbanization and expansion of built-up areas have led to the proliferation of sealed surfaces, including buildings, roads, and parking lots and the need for effective methods to monitor and manage urban growth. Remote sensing techniques, particularly the analysis of satellite images, provide valuable insights into urban dynamics. In the same time, sealed surfaces have profound effects on local climates, hydrological processes, and ecosystem services. Accurate monitoring and assessment of sealed surfaces are essential for urban planning, environmental management, and climate change studies. The Normalized Difference Built-up Index (NDBI) is a spectral index that enables the extraction and quantification of built-up areas and sealed surfaces from satellite imagery. The scientific literature from the last decade proved NDBI as a valuable remote sensing technique for analyzing sealed surfaces and quantifying urbanization (Bhatti & Tripathi, 2014; Ettehadi Osgouei et al., 2019; García & Pérez, 2016; He et al., 2010; Varshney & Rajesh, 2014; Zha et al., 2003).

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NDBI has proven to be effective in monitoring urban expansion over time (Ali Shah et al., 2022; Karanam, 2018; Yasin et al., 2020; Zha et al., 2003; Zheng et al., 2021). Rapid urbanization can lead to land use change, including the conversion of natural habitats and agricultural lands into built-up areas (Dolean et al., 2020). This process can result in habitat loss, fragmentation, and the degradation of ecosystems. By analyzing changes in NDBI values, researchers can quantify the extent and rate of urbanization, identify hotspots of urban growth, and assess land use changes. This information is invaluable for urban planners and policymakers in making informed decisions related to urban development and infrastructure planning. While the NDBI itself does not directly impact the environment, its applications and implications can have both positive and negative effects on the environment.

Thus, it has been demonstrated that built-up areas have a direct impact on the land surface temperatures (Chatterjee & Majumdar, 2022; Mallick et al., 2013; Seun et al., 2022). As sealed surfaces contribute to the urban heat island effect, leading to increased land surface temperatures, NDBI has been combined with thermal remote sensing data to estimate land surface temperatures. This integrated approach provides valuable insights into urban microclimates, heat stress patterns, and the effectiveness of urban heat mitigation strategies (Abir & Saha, 2021; Adeyeri et al., 2017; Guha et al., 2018, 2022; Shahfahad et al., 2020; Zhang et al., 2009). Because the NDBI enables the identification and mapping of sealed surfaces, it can also facilitate the assessment of environmental impacts associated with urbanization. Different studies showed that the NDBI can be useful to evaluate changes in vegetation cover, loss of natural habitats, and the fragmentation of green spaces (Ettehadi Osgouei et al., 2019; Yasin et al., 2020).

This paper aims to present an overview of the calculation methodology and applications of NDBI in mapping soil sealed surfaces in the urban area of Craiova, shedding light on its potential for urban land use analysis.

2. DATA AND METHODS

2.1. Study area

Craiova, one of the largest cities in the south-west part of Romania (one of the seven urban growth poles) registered an intense urban expansion around its rural surrounding areas, increasing also its built-up area within the city limits (Fig. 1).

Craiova has a wide functional urban area (29 local administrative units - LAUs: 3 urban and 26 rural), which almost coincides with its metropolitan area (except 5 LAUs that are not part of the metropolitan area: Coțofenii din Dos, Ghindeni, Goiești, Podari, Robănești) where built-up surfaces increased over time, as urban population started migrating toward the surrounding rural area in search of bigger living places, which determined the increase of the sealed surfaces (new roads, new living spaces, and urban services) especially within the rural settlements in the near vicinity of the city.

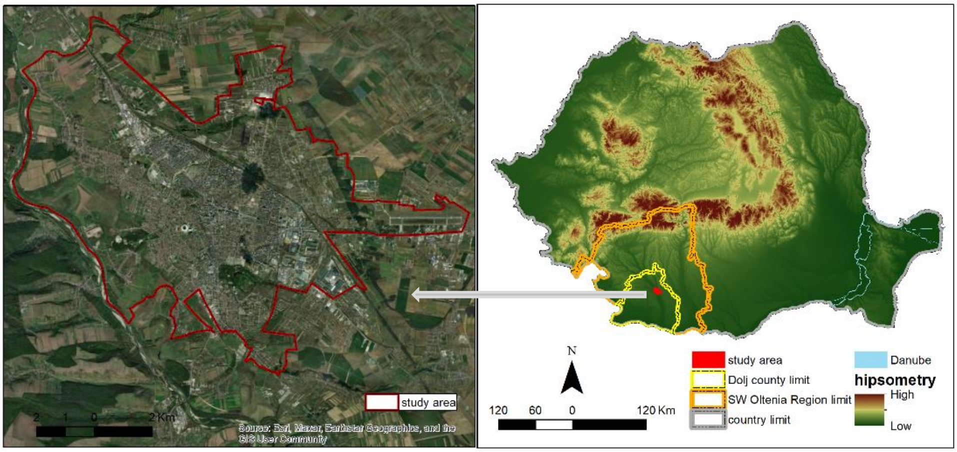

Fig. 1. Location of the study area
(Source: author)

2.2. Data

Obtaining suitable satellite imagery is crucial for accurate NDBI calculations. Various satellite systems provide imagery with different spatial resolutions, temporal frequencies, and spectral bands (Jamei et al., 2019). The choice of data source depends on the study area, research objectives, and availability of data (Ali et al., 2019; Varshney & Rajesh, 2014).

To analyse the dynamics of the built-up area in Craiova city, Landsat satellite TM images (from 2010, 2015 and 2020) are used with the near-infrared (NIR) and shortwave infrared (SWIR) spectral bands suitable for the study area. Raw images were downloaded from USGS Earth Explorer and all the seven bands were stacked to form false color composite image.

2.3. Methods

Before calculating NDBI, satellite imageries were preprocessed for radiometric and geometric corrections, atmospheric correction, and image registration. These processes aim to enhance image quality, minimize geometric distortions, and ensure accurate and reliable results. For image preprocessing and classification tasks the Semi-Automatic Classification Plugin (SCP) from QGIS was used.

NDBI is calculated using multispectral remote sensing data, typically from satellite imagery. It utilizes NIR and SWIR spectral bands to distinguish between built-up areas and non-built-up areas. The NDBI formula is expressed as:

$$\frac{(SWIR-NIR)}{(SWIR+NIR)} \quad (1),$$

where SWIR and NIR represent the reflectance values in the respective bands. Positive NDBI values indicate the presence of built-up areas, while negative values represent non-built-up areas (Institute of Survey Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhon Ratchasima Province, Thailand et al., 2020; Zha et al., 2003).

The last process was the normalization of the NDBI values to a scale ranging from -1 to +1 using the following formula:

$$NDBI = \frac{(NDBI - NDBI_{min})}{(NDBI_{max} - NDBI_{min}} \quad (2),$$

where $NDBI_{min}$ and $NDBI_{max}$ are the minimum and maximum NDBI values within the study area.

For the processing and visualization of the results QGIS 3.22 was used.

3. RESULTS AND DISCUSSIONS

The relationship between increased built-up area and soil sealing is quite direct. As the built-up area expands, the process of soil sealing intensifies. When a city experiences increased urbanization and development, it often involves the construction of buildings, roads, parking lots, and other impervious surfaces. These surfaces, such as concrete and asphalt, cover the natural soil and prevent water infiltration. As a result, the soil becomes sealed, leading to the phenomenon of soil sealing (Peroni et al., 2022; Xiao et al., 2013).

The NDBI measures the degree of urbanization by quantifying the difference between the visible and near-infrared bands of a satellite image. Built-up areas, characterized by high reflectance in the visible spectrum and low reflectance in the near-infrared spectrum, yield higher NDBI values. Vegetation and non-built-up areas, on the other hand, exhibit lower NDBI values due to their higher near-infrared reflectance. By calculating the NDBI, it is possible to differentiate built-up areas from other land cover types (Guha et al., 2018; He et al., 2010).

The data processed showed an increase in the built-up area within the city limits and its surroundings, especially in its eastern and northern parts (Fig. 2).

The biggest increase of soiled sealed areas can be noted in 2015, when large built-up areas can be seen to have appeared in the south-east, north, and some scattered areas in the western part of the city. The expansion of built-up areas continues and, in 2020, new sealed areas can be seen especially in the northern part of the city (Fig. 2). But the dynamics of built-up areas in Craiova is not related to population growth or to an increased economic development. We might take into consideration some expansion of the service sector, especially along the new bypass roads, which led to the construction of commercial buildings and infrastructure to support economic activities. Moreover, the development of infrastructure projects such as the north and east bypass belts triggered the expansion of the city in these two particular directions. The improved infrastructure connectivity caused the occurrence of urban sprawl as people find it more convenient to live in newly accessible areas.

Despite the fact that the population registered a decreasing trend, the increased demand for the new type of individual housing determined the rapid development of real estate investment within the city limits and outer its administrative area. This demand determined developers to undertake construction projects to meet the market needs especially after the end of the economic crisis in 2015.

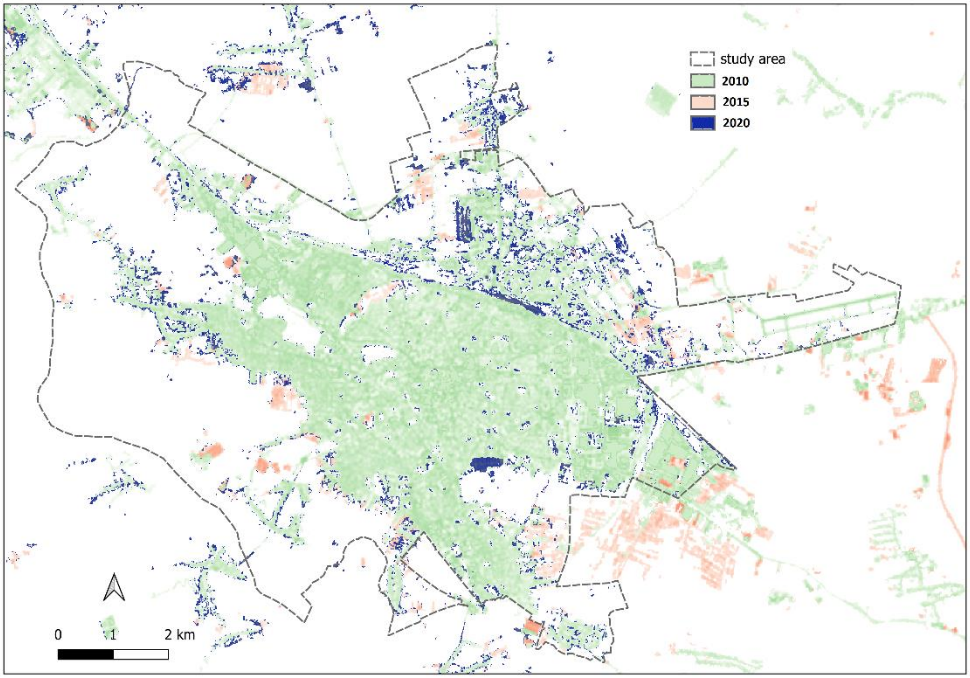

Fig. 2. Dynamics of built-up area in the urban area of Craiova city
(Source: author)

Many old brownfield areas or unused open spaces were converted into built-up areas. Also, the local policies and regulations related to land use, zoning, and urban planning played a significant role in determining the growth of built-up areas, as local authorities allowed the conversion of agricultural or undeveloped land into urbanized areas. This rapid expansion determined the local authorities in 2022 to expand the official limits of the LAU of Craiova city with 3.7 km^2. This is an increase with 4.5% compared to the previous limit of 81.4 km^2. Although the city expanded during the last decade, the population growth did not follow the same increasing trend, decreasing with 6.5% (Table 1).

Table 1. Dynamics of built-up area and population in Craiova city

Craiova city	2010	2015	2020	Dynamics (%)
LAU Area	81.4 km^2	81.4 km^2	81.4 km^2	3.7
Population	312,142	306,619	298,952	-6.5
Built-up area	41.14 km^2	46.43 km^2	47.35 km^2	15.1

(Source: own calculation)

The resulted data show that, despite the fact that the population decreased between 2010 and 2020, the built-up area has increased with 15.1% in the same period. A considerable increase was between 2010 and 2015, when the built-up area increased with 5.3 km^2. This increase rate slowed down in the following five years (Table 1).

Most of the sealed surfaces are covered with residential buildings (collective buildings or single-dwellings), followed by buildings with industrial, public or commercial destination. The transport infrastructure (roads, railroads or the airport) has also an important coverage (about 22% of the sealed surfaces).

We have to understand that this index has limitations and challenges that must be considered when calculated. Mixed pixel problem is one of the challenges that we may encounter in calculating NDBI when pixels contain a mixture of built-up and non-built-up materials, resulting in inaccurate classification. This issue can be addressed by using advanced image processing techniques and higher spatial resolution data (Zheng et al., 2021).

The NDBI values can also be influenced by seasonal variations, atmospheric conditions, and changes in land cover. These factors need to be considered when interpreting NDBI results over different time periods (Jamei et al., 2019).

Another issue may arise from geometric distortions, which can affect the accuracy of NDBI calculations. This is why image rectification is recommended to correct these distortions, thus ensuring accurate and precise analysis (Fariz & Faniza, 2023; Vorovencii, 2020).

Urban areas created through human development often have a limited capacity to support diverse ecosystems compared to natural environments; however, the incorporation of green spaces, parks, and urban forests can enhance biodiversity and provide ecological benefits. The NDBI can assist in identifying areas where green infrastructure can be implemented, promoting ecological connectivity and supporting urban biodiversity. In the same time, the information derived from NDBI analysis is valuable for urban planning and infrastructure development. By understanding the distribution and density of built-up areas, authorities can make informed decisions regarding transportation networks, utilities, and services. Proper planning can minimize the environmental impact of infrastructure development, including reduced habitat destruction and optimized resource usage. This information can be used in environmental impact assessments and the development of sustainable urban planning strategies.

4. CONCLUSIONS

The Normalized Difference Built-up Index (NDBI) has become an invaluable tool for assessing sealed surfaces and monitoring urban expansion. Its ability to extract information about built-up areas from remote sensing data provides essential insights into urbanization processes and their impacts on the environment. While NDBI has several limitations, ongoing advancements in remote sensing technology and data processing techniques hold promise for further improving its accuracy and applicability. Integrating NDBI with other urban indicators can enhance our understanding of urban dynamics and support informed decision-making for sustainable urban development.

Increasing built-up areas inside Craiova city and in its surroundings can give rise to various social and economic problems associated with urban expansion like housing affordability, displacement and gentrification, social segregation, increased demand for public services and infrastructure costs. Environmental problems are also created by urban expansion and the occurrence of new soil sealed surface: interruption of water circuit in nature, increase urban heat island effect. New housing increases the energy consumption and emissions causing air pollution, while local water resources are also affected by a reduced water infiltration, increased stormwater runoff (frequent flush floods are reported on streets during heavy rains), causing water pollution and straining the water management systems. Also, the growth of built-up areas tends to exacerbate the urban heat island effect.

Using modern technologies like GIS and remote sensing can help local authorities acknowledge better the real dimension and implications of the urban expansion. Decision makers should understand that addressing these challenges requires comprehensive urban planning, sustainable development practices, and the integration of social, economic, and environmental considerations. This involves promoting affordable housing, inclusive communities, green infrastructure, energy-efficient design, and participatory decision-making processes to create livable and sustainable cities.

To mitigate the negative impacts of soil sealing resulting from increased built-up areas, sustainable urban planning and design practices should be implemented. It is important for city planners, developers, and policymakers to prioritize sustainable land use practices that minimize soil sealing while supporting the needs of urban development and the preservation of natural resources.

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