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# Temporal Analysis of Multispectral Satellite Data for the Purpose of Urbanization Monitoring

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**Abstract**

Monitoring the urbanization process and early detection of illegal construction should enable meaningful urban planning and the protection of natural and cultural features of the community. There is a major problem of illegal construction in the Republic of Croatia. In 2023 alone, according to a report by the State Inspectorate of the Republic of Croatia, a total of 4,774 inspections were carried out on the territory of the Republic of Croatia, and 1,089 inspection procedures were initiated due to violations of construction regulations. The aim of this paper was to examine and determine the possibilities of applying remote sensing methods in the early detection of areas under construction or other types of devastation. The evaluation of the quality and usability of the results refers to reliability of the detection of areas under construction using the images of the Sentinel-2 and PlanetScope satellite systems. In order to detect those areas, ten spectral indices were for two reference dates one in 2017 and 2021 (nine indices for Sentinel-2 and one for Planetscope). The results of this research include analysis of spectral indices for detection and identification of land parcels that exhibit land cover changes from natural to human construction. The city of Solin and Podstrana municipality (near Split, Croatia), with its wider surroundings, were selected for the research area. The best results were achieved with the difference of NDVI spectral indices calculated using the spectral channels of the Sentinel-2 and PlanetScope satellite systems. Achieved results, showed also that the spatial resolution of the used spectral bands (3 m PlanetScope and 10 m Sentinel-2) did not have a major impact on the accuracy of detection for this specific application.

## 1. INTRODUCTION

The tendency towards urban sprawl and excessive apartment building (especially in coastal areas) has led to the uncontrolled expansion of urban space and significant loss of vegetation in all urban areas of the Republic of Croatia. Based on 1089 inspection procedures for violation of building regulations, 791 decisions were made on the removal of illegal buildings (State Inspectorate of the Republic of Croatia, 2024) only in 2023. Illegal construction undermines the quality of life of individuals and communities because it generally involves disregard for urban planning rules, damages the environment, reduces green areas, increases the risk of urban heat islands, and burdens municipal infrastructure.

Automatic detection of illegal constructions supported by information from satellite images is an important issue, both for authorized government agencies and for the research community. This problem combines the challenge of automatic detection of areas with land cover changes from natural to human construction by means of satellite images and verification of extracted data with cadastral or spatial plans and building permits. Detection and extraction of buildings from satellite images is a very complex process that depends on the background and the environment in which the buildings are built (Ostankovich and Afanasyev, 2018). Namely, objects of interest (buildings) and their surroundings can be characterized with different intensities and spectral responses.

Collecting and updating data on changes in the urban environment across the country is a laborious and time-consuming process that requires huge investments in human and material resources of government and local institutions. Due to these facts, satellite images are increasingly used today to monitor urbanization and changes within urban areas. The use of remote sensing data significantly speeds up the monitoring process and reduces human resources in the process of obtaining results but requires experts in the field of interpretation and processing of digital images (Haas et al., 2015, Ion-Dorinel et al. 2025). The results of remote sensing methods can provide timely information about changes in urban land cover (Furberg et al., 2019).

Various studies can be found on this topic with different approaches to the problem, such as the use of linear classifiers and self-organizing maps (Persson et al., 2005), geometric and spectral (radiometric) features, and machine learning algorithms (Wei and Prinet, 2005, Sirmacek and Unsalan, 2008). Methods can also be found that combine GIS information about the urban area of interest with high and very high-resolution image data to improve detection accuracy (Guo et al., 2016).

The aim of this research is to combine GIS information about the urban area of interest with high and very high-resolution image data to assess the possibility of applying remote sensing methods in detection and identification of (illegal) human construction areas. The influence of the spatial resolution to the accuracy and reliability for urbanization monitoring was studied by comparing data of commercial PlanetScope satellite system (very high-resolution satellite imagery with spatial resolution of 3 m) and free, full and open Sentinel-2 satellite system (high-resolution satellite imagery with the highest spatial resolution of 10 m).

## 2. MATHERIALS AND METHODS

The city of Solin and Podstrana municipality (Croatia) were chosen as the research area, since they represent areas with intensive construction work, so it was easy to find cadastral plots where construction of residential buildings occurred during the timespan of the analyzed images. The 17 cadastral plots with confirmed construction work served as reference values and analysis of calculated spectral indices, all located in city of Solin area. Spectral indices were tested on cadastral plots with confirmed changes in land cover from natural to human construction. The accuracy assessment was carried out by visual interpretation of aerial images having better spatial resolution and analysis of cadastral and building permit registers. The most reliable indices were selected for a verification (blind) test that was carried out at Podstrana municipality.

### 2.1 Study Area

The town of Solin is in the southern part of the Republic of Croatia, on the Adriatic Sea coast, on a karst soil with scarce vegetation with a Mediterranean climate. A complicating circumstance in the research is precisely the rugged terrain on which the city of Solin developed, and the very scarce vegetation. In the spatial-economic structure of the settlement, industry and traffic dominate. Accordingly, most of the coastal belt is planned and built in the function of working and warehouse-sisterly zones, and zones of traffic activities. In addition to industrial and traffic objects, one of the negative features of the settlement parts is the lack of urban public spaces (squares, pedestrian zones, urban greenery). The area of the city is a relief diverse space that plays flat and slightly tilted parts in the coastal part and a steep and very steep terrain extending towards the north and eastern edges of the city (more distant from the coast). Because of the good orientation of the terrain in relation to the sea and economic benefits of tourism activities, the problem of illegal construction has arisen.


Figure 1. RGB image of the 2017 Planetscope Satellite System, with a mask (green polygon) that defines the area of analysis and 17 analyzed cadastral parcels marked with red color.

Exact spatial extent of 17 cadastral parcels (Figure 1) were downloaded from the "Spatial Planning Information System", which shows data from the Ministry of Physical Planning, Construction and State Property with the cover of construction and location permits (ISPU, 2025).

### 2.2 Input Data

For the purposes of this research, multispectral images of the satellite systems Sentinel-2 and the PlanetScope were analyzed (Table 1). Close dates between images of satellite systems Sentinel-2 and PlanetScope were selected to enable comparison between the sensors, as well as to better analyze the influence of spatial resolution on the reliability of the results obtained.

| Satellite system | Acquisition date |
|---|---|
| Sentinel-2 | 18th May 2017 |
| Sentinel-2 | 22nd May 2023 |
| PlanetScope | 17th May 2017 |
| PlanetScope | 23rd May 2023 |

Table 1. Satellite system and collecting dates.

In addition to the satellite imagery, the official digital orthophoto (DOP) of the State Geodetic Administration for 2017, 2019 and 2021 with a spatial resolution of 0.5 m; and imagery available in Google Earth, which cover the analyzed period were used as a reference data for verification purposes.

### 2.3 Spectral indices

This methodology for assessing the changes of land cover from natural to human construction is based on spectral indices calculated from satellite imagery (Sentinel-2 and PlanetScope).

Spectral indices are mathematical expressions that combine reflectance data from two or more spectral bands to highlight specific features or phenomena on the Earth's surface (Montero et al., 2023). Within this research, nine spectral indices were selected as relevant from literature review (Table 2). Some of the indices were originally developed for other satellite systems like Landsat Thematic Mapper, but due to its compatibility with Sentinel-2 spectral bands those indices were adapted accordingly. All nine spectral indices were calculated for Sentinel-2, while for Planetscope imagery only NDVI was determined.

Selected spectral indices (Table 2) may be grouped in three categories: five built-up indices NDBI, NBI, NBAI, BRBA, BAEI; three soil indices BSI, DBS, NDT; and one vegetation index NDVI. The common characteristic of the selected soil and built-up spectral indices is that they were calculated using short infrared and near infrared spectral bands, because the built areas have a higher reflection in a short infrared than in a near infrared bands (Akib, et al., 2021). Due to the difference in spatial resolution of Sentinel-2 bands (10 m, 20 m, 60 m), bands with 20 m and 60 m resolution were resampled to 10 m using Nearest Neighbour resampling method.

Spectral indices were calculated for two dates for each analysed satellite (Table 1), and then a difference in spectral indices over a defined timespan was analyzed. Obtained differences, were integration with open data in the form of digital orthophoto and official registers of construction permits and cadastral data to assess the accuracy of the achieved results.

| Spectral index | Expression | Reference |
|---|---|---|
| Normalize difference build-up index (NDBI) | $NDBI = \frac{B11 - B8}{B11 + B8}$ | Kuc and Chormański, 2019 |
| New built-up index (NBI) | $NBI = \frac{B4 * B11}{B8}$ | Jieli et al., 2010 |
| Normalized built-up area index (NBAI) | $NBAI = \left(B12 - \frac{B11}{B3}\right) / \left(B12 + \frac{B11}{B3}\right)$ | Waqar, 2012 |
| Band ratio for built-up area (BRBA) | $BRBA = \frac{B4}{B11}$ | Waqar, 2012 |
| Built-up area extraction index (BAEI) | $BAEI = \frac{B4 + L}{B3 + B11}$ | Bouzekri et al., 2015 |
| Bare soil index (BSI) | $BSI = \frac{(B4 + B11) - (B2 + B8)}{(B4 + B11) + (B2 + B8)}$ | Nguyen et al., 2021 |
| Dry bare-soil index (DBSI) | $DBSI = \left(\frac{B11 - B3}{B11 + B3}\right) - \left(\frac{B8 - B4}{B8 + B4}\right)$ | Rasul et al., 2018 |
| Normalized difference tillage index (NDTI) | $NDTI = \frac{B11 - B12}{B11 + B12}$ | Van Devente et al., 1997 |
| Normalized difference vegetation index (NDVI) | $NDVI = \frac{B8 - B4}{B8 + B4}$ | Rouse et al., 1973 |

Table 2. Spectral indices used in the research, band numbers (labels) in expressions correspond to the Sentinel-2 spectral bands.

## 3. RESULTS AND DISCUSSION

One of the main results of this research was to highlight the indices that achieved the best results for the purpose of detecting land parcel that exhibited land cover changes from natural to construction.

### 3.1 Visual analysis of Spectral Index Difference

On cadastral parcels with confirmed change in land cover between reference dates in 2017 and 2021, the results obtained for the calculated differences in spectral indices were evaluated through visual analysis. Visual analysis means that the spectral indices were displayed over a DOP with a spatial resolution of 0.5 m (Figure 2).

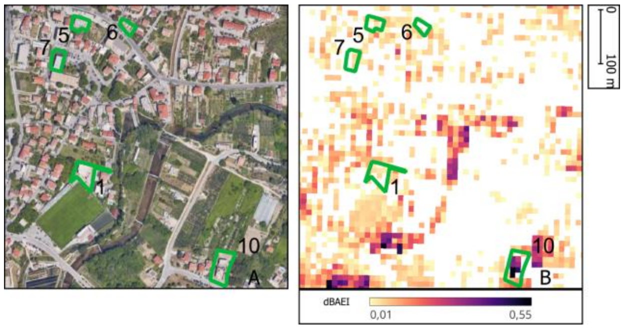


Figure 2. A) Google Earth satellite image from October 2022, B) BAEI spectral index difference (calculated using the spectral bands of the Sentinel-2). Reference cadastral parcels are marked in green.

The difference image (difference from May 2021 and 2017, Table 1) of the BAEI (Figure 2B) did not achieve satisfactory results, because only land parcel marked with number 10 was correctly highlighted, while for remaining parcels index difference scored low values.

With the difference image of the NDTI (Figure 3), it can be seen that the detection of human construction is successful for larger buildings (Figure 3A), however, the detection of individual residential objects may pose a challenge (Figure 3B). That may be due to use of only the Sentinel-2 spectral bands with spatial resolution of 20 m.

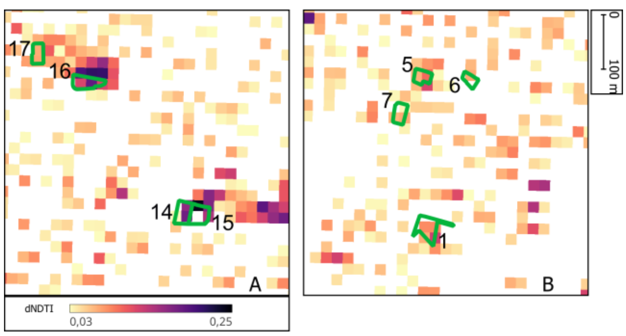


Figure 3. NDTI difference images (Sentinel-2 bands) A) Close-up with larger reference cadastral parcels, B) Close-up with smaller reference cadastral parcels. Reference cadastral parcels are marked in green.

NDBI and DBSI difference images showed similar results on reference land parcels (Figure 4). However, by their visual comparison in surrounding areas, it can be seen that the DBSI (Figure 4B) difference may generally provide results with lower false alarm rate than the NDBI (Figure 4A). It is also worth noting that both spectral indexes did not show good results in cases where smaller buildings were built on mixed-use land.

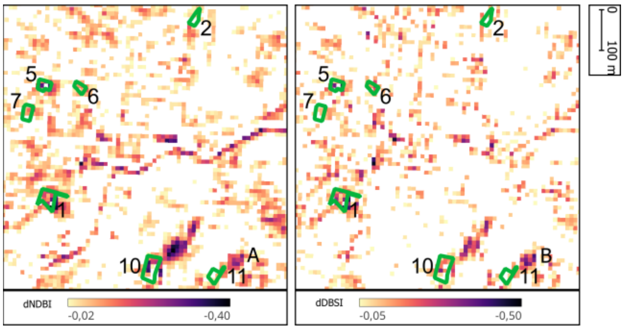


Figure 4. A) NDBI difference, B) DBSI difference (Sentinel-2 bands). Reference cadastral parcels are marked in green.

Generally, BRBA, NBAI and BSI differences provided similar results on reference land parcels. But it should be emphasized that in the BRBA and NBAI difference images, changes in land cover on gravel terrain have been successfully detected in some cases (Figure 5), and according to previous research, such detection represents one of the greatest challenges.

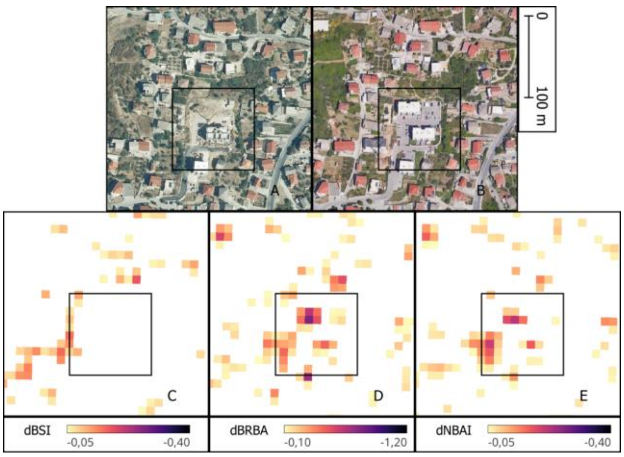


Figure 5. A) Digital orthophoto from 2017, B) Google Earth image from October 2022, C) BSI difference, D) BRBA difference, E) NBAI difference (Sentinel-2 bands).

In the NBI difference image, land cover changes from natural to human construction can be clearly identified (Figure 6), and the results suggest that it may result with low false alarm rate by taking in the account wider area.

As the city of Solin is located in the area of the Mediterranean climate where some type of vegetation is present on almost all areas that have not been built, the difference in the spectral index of the NDVI obtained promising results on reference cadastral parcels. Although the spatial resolution of the NDVI for the data of the PlanetScope satellite system is 3 m, and 10 m for the Sentinel-2 data, the results are comparable for detection of residential buildings. However, Planetscope may be used for detection of changes for smaller objects like garages, but this was not analyzed in the scope of this research.

By analyzing data for reference cadastral parcels, it was observed that the best results were achieved by using the NDVI difference with the both data of the PlanetScope and Sentinel-2, followed by NBI, BRBA, BSI and NBAI differences.

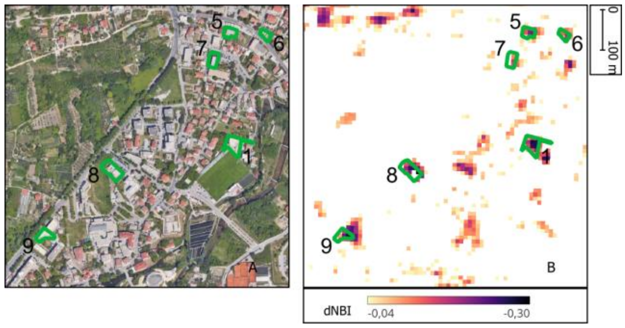


Figure 6. A) Google Earth image from October 2022, B) NBI difference (Sentinel-2 bands). Reference cadastral parcels are marked in green.

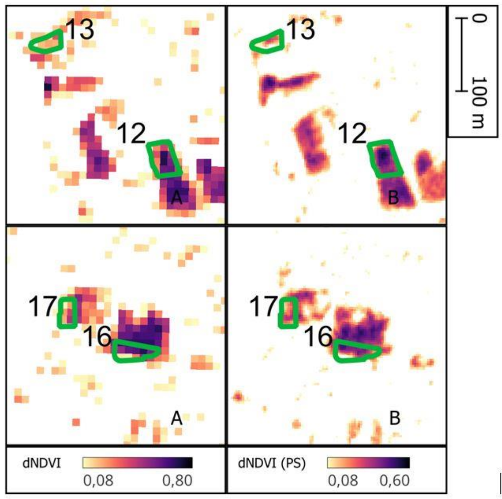


Figure 7. A) NDVI difference (Sentinel-2 bands), B) NDVI difference (PlanetScope bands).

## 3.2 Methodology verification

After the described analysis, the model was verified in another area with a blind test. The verification model was conducted with five selected spectral indices (NDVI – calculated with both Sentinel-2 and Planetscope, NBI, BRBA and NBAI) which achieved the best results presented in previous paragraph. The blind test was conducted in the Podstrana municipality (Figure 8), Croatia. One urban and one rural location within the municipality were selected (Figure 8).

Obtained results are shown on Figure 9 and Figure 10. By analyzing the results, it may be concluded that the applied methodology performs better in rural than highly urban areas. In analyzed rural scene there were 4 correct detection and 1 false alarm with no missed detection (Figure 9). On urban scene equally good results were not achieved, as there were less correct detection rate as well as missed detection appeared with false alarms.

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Figure 8. Area of interest in the municipality of Podstrana (red rectangles: lower = urban, upper = rural).

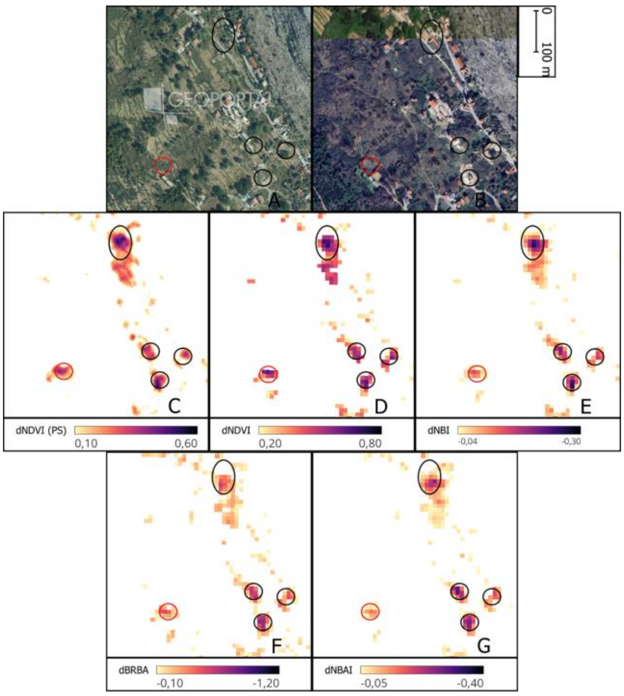


Figure 9. Detection of changes in construction in the rural part of the municipality of Podstrana. Black circles indicate successful detections, and red circles indicate false alarms. A) Digital orthophoto from 2017, B) Google Earth image from October 2022, C) NDVI difference (PlanetScope), spectral index differences for Sentinel-2 data: D) NDVI, E) NBI, F) BRBA, G) NBAI.

### 3.3 Discussion

The best results were achieved with the NDVI difference calculated using both Sentinel-2 and PlanetScope sdata. Achieved results that for this type of research, the spatial resolution of the spectral bands used (3 m PlanetScope and 10 m Sentinel-2) did not have a major impact on the accuracy of detection.

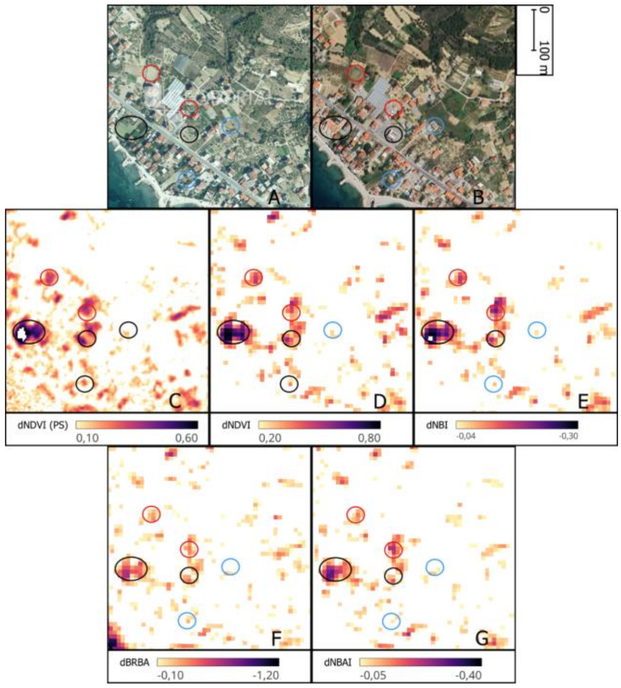


Figure 10. Detection of changes in construction in the urban part of the municipality of Podstrana. Black circles indicate successful detections, blue circles missed detections and red circles indicate false alarms. A) Digital orthophoto from 2017, B) Google Earth image from October 2022, C) NDVI difference (PlanetScope), spectral index differences for Sentinel-2 data: D) NDVI, E) NBI, F) BRBA, G) NBAI.

Implemented verification procedure included five spectral indices (NDVI – PlanetScope and Sentinel-2, NBI, BRBA and NBAI) that gave the best results in the previous analysis. Verification results showed that the purpose of this method for detection of potenitally illegal construction may be very practical in rural areas, where the difference images were compared with the building permit register from the ISPU, and it was shown that on an area of roughly 6 hectares, no building permit was issued for three newly built buildings that were detected and identified from satellite data.

It should be also emphasized here that the research was conducted on challenging karst terrain with sparse vegetation, which greatly affects the radiometric recognition of locations that were not covered by vegetation before construction.

## 4. CONCLUSION

The purpose of this method was to implement satellite data for the needs of urbanization monitoring and detection of possible illegal construction through comparison with official cadastral and building permit registers.

Achieved results of proposed approach have proven to be very practical in rural areas. From the obtained results, it can be concluded that for areas with a Mediterranean climate, the use of differences of NDVI and NBI spectral indices gives promising results that could be of great use for urbanization monitoring and the initial control of construction areas.

Proposed methodology uses spectral indices are not computationally complex and may be easily implemented. In this work, only two images in span of 4 years were used for difference calculation, however, in future work a system may be implanted that for every cadastral parcel updates spectral indices for every satellite revisit. By doing so, detection accuracy may be significantly improved. Also, instead of simple satellite indices, a more complex approach could be used by implementing spectral unmixing techniques to achieve subpixel detection and accuracy improvement in urban areas.

## REFERENCES

Akib, J., Qimin, C., Hao, P., Orhan, A., Yan, L., Iffat, A., Enamul, H., Yeamin, A., Nayyer, S., 2021. Photogrammetric Engineering & Remote Sensing, Vol. 87, No. 7, July, pp. 1–xxx. 0099-1112/21/1–xxx, doi: 10.14358/PERS.87.7.1

Bouzekri, S., Lasbet, A.A., Lachehab, A., 2015. A New Spectral Index for Extraction of Built-Up Area Using Landsat-8 Data. J Indian Soc Remote Sens 43, 867–873. https://doi.org/10.1007/s12524-015-0460-6

Furberg, D., Ban, Y., Nascetti. A., 2019. Monitoring of Urbanization and Analysis of Environmental Impact in Stockholm with Sentinel-2A and SPOT-5 Multispectral Data. Remote Sensing, 11(20), 2408. doi:10.3390/rs11202408

Guo, Z., Du, S., Li, M., Zhao, W., 2016. Exploring gis knowledge to improve building extraction and change detection from vhr imagery in urban areas, International Journal of Image and Data Fusion, vol. 7, pp. 42–62.

Haas, J., Furberg, D., Ban, Y., 2015. Satellite monitoring of urbanization and environmental impacts—A comparison of Stockholm and Shanghai. International Journal of Applied Earth Observation and Geoinformation, 38, 138–149. doi:10.1016/j.jag. 2014.12.008

Ion-Dorinel, F., Cune, C., Pop, F., 2025. Cloud-based solution for urbanization monitoring using satellite images, Future Generation Computer Systems, Volume 164, March, 107579

ISPU., 2025. Physical Planning Information System - Ministry of Physical Planning, Construction and State Property, https://ispu.mgipu.hr/#/ , (01th March 2025)

Jieli, C., Manchun, L., Yongxue, L., Chenglei S., Wei H., 2010. Extract residential areas automatically by New Built-up Index, 2010 18th International Conference on Geoinformatics, Beijing, China, 2010, pp. 1-5, doi: 10.1109/GEOINFORMATICS.2010.5567823

Kuc, G., Chormański, J., 2019. Sentinel-2 Imagery For Mapping and Monitoring Imperviousness In Urban Areas, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-1/W2, doi: 10.5194/isprs-archives-XLII-1-W2-43-2019

Montero, D., Aybar, C., Mahecha, M.D., Martinuzzi, F., Sochting, M., Wieneke, S., 2023. A standardized catalogue of spectral indices to advance the use of remote sensing in Earth system research. Sci Data 10, 197. https://doi.org/10.1038/s41597-023-02096-0

Nguyen, C.T.; Chidthaisong, A.; Kieu Diem, P.; Huo, L.-Z., 2021. A Modified Bare Soil Index to Identify Bare Land Features during Agricultural Fallow-Period in Southeast Asia Using Landsat 8. Land, 10, 231. https://doi.org/10.3390/land10030231

Ostankovich, V., and Afanasyev, I., 2018. Illegal Buildings Detection from Satellite Images using GoogLeNet and Cadastral Map. International Conference on Intelligent Systems (IS). doi:10.1109/is.2018.8710565

Persson, M., Sandvall, M., Duckett, T., 2005. Automatic building detection from aerial images for mobile robot mapping, in Computational Intelligence in Robotics and Automation, 2005. CIRA Proceedings. 2005 IEEE International Symposium on, pp. 273–278, IEEE

Rasul, A., Balzter, H., Faqe Ibrahim, G.R., Hameed, H.M., Wheeler, J., Adamu, B., Ibrahim, S., Najmaddin, P.M., 2018: Applying Built-Up and Bare-Soil Indices from Landsat 8 to Cities in Dry Climates, Land 7(3), DOI: 10.3390/land7030081

Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W., 1973. Monitoring vegetation systems in the Great Plains with ERTS. In Proceedings of the 3rd Earth Resources Technology Satellite-1 Symposium (Vol. 1, pp. 309–317). NASA SP-351.

Sirmacek, B. and Unsalan, C., 2008. Building detection from aerial images using invariant color features and shadow information, in Computer and Information Sciences, 2008. ISCIS'08. 23rd International Symposium on, pp. 1–5, IEEE.

State Inspectorate of the Republic of Croatia, 2024. Annual report on the work of the State Inspectorate for 2023, source: https://dirh.gov.hr/pristup-informacijama/planovi-i-izvjesca/planovi-i-izvjesca-284/284 (01st March 2025)

Strashok, O., Ziemiańska, M., Strashok, V., 2022. Evaluation and Correlation of Sentinel-2 NDVI and NDMI in Kyiv (2017–2021), Journal of Ecological Engineering 2022, 23(9), 212–218 https://doi.org/10.12911/22998993/151884 ISSN 2299–8993, License CC-BY 4.0

Van Deventer, A. P., Ward, A. D., Gowda, P. H., Lyon, J. G., & Nolin, J. M., 1997. Using Thematic Mapper Data to Identify Contrasting Soil Plains and Tillage Practices. Photogrammetric Engineering & Remote Sensing, 63(1), 87–93

Waqar, M.M., Mirza, J.F., Mumtaz, R., Hussain, E., 2012: Development of New Indices for Extraction of Built-Up Area & Bare Soil from Landsat Data, 1: 136, doi:10.4172/scientificreports.136

Wei, L., Prinet, V., 2005. Building detection from high-resolution satellite image using probability model, in In Proceedings of the IEEE International Geoscience and Remote Sensing Symposium, Seoul, Korea, Citeseer