SATELLITE DATA AND CITIZENS SCIENCE FOR SUSTAINABLE CITIES

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ABSTRACT

The vast amount of satellite data empowers scientists to monitor, analyze, and design the urban environment considering comprehensive criteria. There are still some challenges in data analysis of urban areas due to low resolution of open satellite data, high cost of commercial satellite data, and noise (impulse, speckles, clouds, etc.). Citizen data collection could complement satellite data to get more precise information that can help decision makers to gain a better liveable urban environment. This study examines the potential for widespread use of citizen and satellite data to monitor urban environments, with a particular emphasis on air quality and vegetation monitoring. Due to short revisit time and higher spatial resolution satellite data provided by the European Space Agency have been used to monitor vegetation through vegetation multispectral indices (NDVI, NDRE, RVI, etc.) and air quality (SO_2, HCHO, NO_X, etc.). While satellite data can lead to general conclusions of vegetation condition or air quality in a city, citizen data can identify specific problems that are beyond the `satellite's eyes`. Some initiatives engage citizens to collect data of urban biodiversity or monitor air quality. Voigt-Heucke et al. (2023) recognized 35 citizen science projects involved in monitoring and conserving urban biodiversity only in Germany. The European Environment Agency (2019) published the Report Assessing Air Quality through Citizen Science and emphasized the possibility of using simple, standardized measurement devices in air monitoring. The aim of this research is to identify the potential for integrating citizen and satellite data in urban planning, especially to monitor vegetation and air quality. Relevant published articles are analyzed and summarized to review previous experience in combining satellite and citizen data. Also, Sentinel 2 and Sentinel 5 Precursor data and Qgis open software are used to express the green area and air quality in Belgrade in 2016 and 2023. .

KEYWORDS _ *Satellite data, citizen science, urban vegetation, air quality*

INTRODUCTION

According to the United Nations (2019), approximately 55% of the global population resides in urban areas, with projections indicating that this figure will exceed 68% by 2050. The growth of the urban population has led to increasing concerns about environmental conditions in cities, particularly the detrimental effects of pollution on human health and urban biodiversity. Mitigating these negative impacts necessitates the implementation of high-quality monitoring systems across all components of the urban environment. Lima et al. (2025) conducted an analysis of the progression of urban ecological quality research from 1997 to 2023 and concluded that it has expanded significantly "driven by technological advancements, global collaboration, and alignment with policy goals like the UN Sustainable Development Goals (SDGs)". Despite the increasing volume of research, significant challenges persist due to data deficiencies, particularly in developing countries. To bridge this gap, open-access satellite data can be utilized for urban environmental analysis; however, its lower spatial resolution may constrain precision. Xu et al (2022) emphasized the challenges of application of Sentinel 2 satellite data in land cover mapping: the spatial `mixel-pixel` challenge ("different land cover types often coexist within the spatial extent covered by a single pixel"), the spectral `variability` challenge ("variability within a single land cover class (within-class variability) and the resemblance of reflectance characteristics among different classes (between-class similarity)") and the uncertainty in the use of image time series for land cover mapping. Schneider et al. (2021) estimate that gaps in Sentinel-5 data primarily occur in high-latitude regions, where frequent cloud cover and high solar zenith angles are common. Citizen science initiatives can serve as a valuable complementary data source to overlap the gap of satellite data.

This study explores the potential for integrating satellite remote sensing data with citizen science observations to monitor air quality and urban vegetation. The analysis is conducted using a case study area delineated by the administrative boundaries of Belgrade, the capital city of the Republic of Serbia.

METHODOLOGY

A literature review is employed as a scientific method to evaluate the integration of satellite data and citizen science for monitoring air quality and vegetation in urban environments. The case study focuses on the city of Belgrade, utilizing data from the Sentinel-2 and Sentinel-5P satellites. Figure 1 illustrates the geographical location of the study area within Europe.

QGIS 3.36.3 software is used for the extraction, integration, and analysis of nitrogen dioxide (NO_2) concentrations and the Normalized Difference Vegetation Index (NDVI). Satellite data were obtained from the Copernicus Data Space Ecosystem, a user-friendly platform developed by the European Space Agency.

NO_2 concentration levels in Belgrade are derived from georeferenced satellite imagery, using raw NO_2 values (measured in mol/m²) obtained from Sentinel-5P and processed directly within QGIS.

NDVI values are calculated in QGIS using Band 8 (near-infrared) and Band 4 (red) from Sentinel-2A imagery. NDVI is a widely used vegetation index derived from the near-infrared (NIR) and red (RED) spectral bands (Rouse et al., 1974), calculated as:

$$NDVI = (NIR - RED) / (NIR + RED)$$

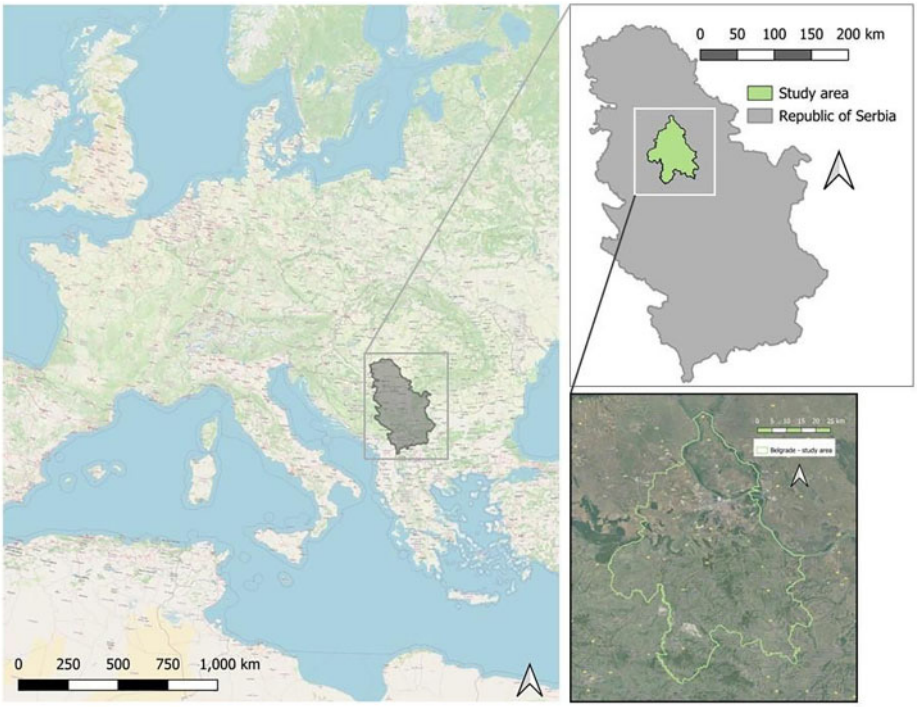


Figure 1: Case study area – City of Belgrade (Sources: Basemaps: Open Street Map, Google Maps Satellite Imagery; Republic of Serbia and Belgrade Administrative Boundaries: https://a3.geosrbija.rs/, Software used to process the data: QGIS 3.36.3)

RESULTS AND DISCUSSION

Figure 2 illustrates nitrogen dioxide (NO_2) concentrations over Belgrade on several specific dates, selected at random to demonstrate how Sentinel-5P data can be utilized to assess air pollution in urban environments. The data were obtained from the Copernicus Data Space Ecosystem, providing analytical, georeferenced imagery of raw NO_2 values measured in mol/m². The images were processed and analyzed using QGIS version 3.36.3.

The results indicate the presence of a pollution hotspot within the urban area. Among the selected dates, the highest NO_2 concentration was recorded on January 2, 2020, while the lowest was observed on January 1, 2023. The dataset's spatial resolution is approximately 2.5 x 2.5 km. Notably, a significant portion of data was missing on January 2, 2020.

Sentinel-5P offers a continuous time series of nitrogen dioxide (NO_2) measurements from April 30, 2018, to the present, making it a valuable dataset for long-term analysis of air pollution trends in Belgrade. However, due to its relatively coarse spatial resolution, the data primarily provide a macroscopic view of atmospheric NO_2 distribution and may not capture finer-scale variations necessary for detailed local-level assessments.

To address limitations in satellite-derived air quality data—particularly regarding spatial and temporal resolution—citizen science initiatives can provide a valuable complementary data source. In Belgrade, multiple initiatives actively involve the public in air quality monitoring using specialized devices. One prominent example is the Klimerko community, which offers an open-source, do-it-yourself (DIY) air quality monitoring system capable of measuring particulate matter (PM), temperature, humidity, and atmospheric pressure. Dozens of these monitoring units are deployed throughout Belgrade, with additional installations across the Republic of Serbia and Bosnia and Herzegovina (Klimerko. 2025).

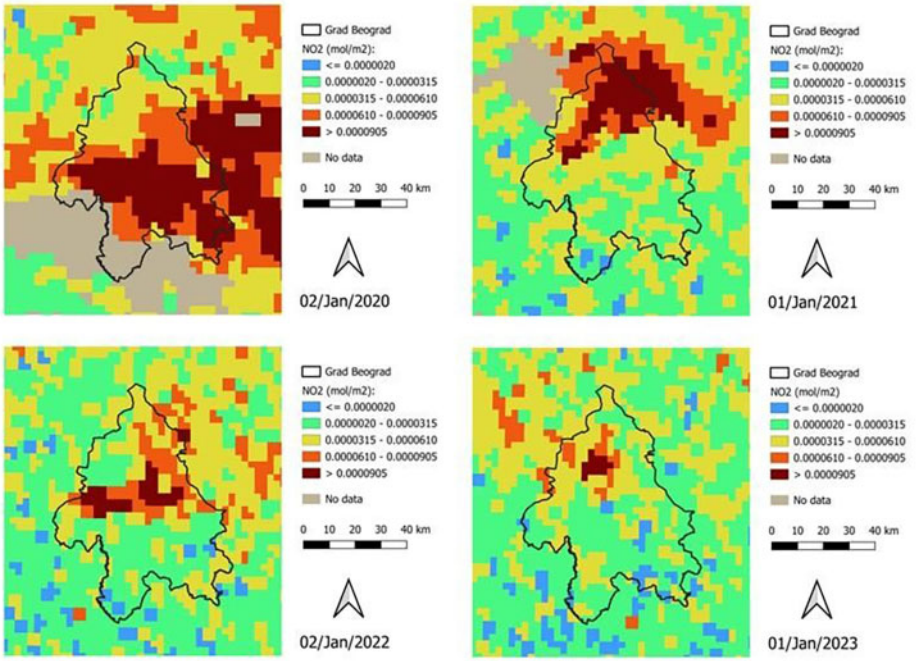


Figure 2: Sentinel-5P satellite data on NO_2 levels in Belgrade (Sources: Sentinel 5P data: https://dataspace.copernicus.eu/, Belgrade Administrative Boundaries: https://a3.geosrbija.rs/, Software used to process the data: QGIS 3.36.3)

Additionally, the Health and Environment Alliance (HEAL) initiated a community-based air pollution monitoring program in 2017, with a primary focus on measuring concentrations of fine particulate matter (PM2.5) (Health and Environment Alliance. 2018.). The Belgrade Open School, through its *Together for Environment* initiative, has supported the expansion of the citizen-based air quality monitoring network by distributing an additional 200 sensors to communities across Serbia that previously lacked air quality measurement infrastructure. (Za životnu sredinu. 2023). Also, several global initiatives include contributions from the Republic of Serbia. One such initiative is Sensor. Community, a worldwide open-data network comprising 11,836 active sensors across 78 countries, including Serbia, for the monitoring of particulate matter (PM2.5) (Sensor.Community. 2023).

Currently, no known initiative specifically integrates citizen-generated air quality data with satellite observations for the city of Belgrade or Republic of Serbia. However, there are some initiatives in Europe and worldwide that use citizen data to complement satellite observations. A notable example is NASA's GLOBE Observer program, one of the longest-running and most consistent citizen science initiatives. It provides a mobile application that enables volunteers to collect georeferenced data on cloud cover, mosquito habitats, land cover, and tree height (GLOBE Observer. 2023). These observations are systematically compared with data acquired by NASA missions. In the context of air quality, GLOBE Observer supports the collection of data related to dust events, which are integrated with satellite-derived information to improve the accuracy and spatial resolution of atmospheric models (GLOBE Observer. 2022).

Figure 3 presents NDVI (Normalized Difference Vegetation Index) values for selected dates during May and June from 2017 to 2023. These late spring dates were carefully chosen to minimize the influence of seasonal phenological variations—namely, to ensure that deciduous tree canopies were fully developed and that agricultural fields had not yet been harvested. Dates were further selected based on low cloud cover to ensure data quality.

Land cover classification follows the scheme provided by the Copernicus Browser. According to this classification, NDVI values below -0.1 are interpreted as water bodies; values between -0.1 and 0.1 correspond to barren land or rocky surfaces; values ranging from 0.2 to 0.4 are indicative of grasslands and shrublands; and values exceeding 0.4 are associated with forested areas (Sentinel Hub. 2017).

Sentinel-2 satellite data have been available as open-access resources since October 2016, providing continuous coverage. Analysis indicates that NDVI values are generally higher in June compared to May. This temporal variation can potentially mislead interpretations related to land cover changes or vegetation condition assessments. To mitigate such limitations, citizen science initiatives can complement satellite-based monitoring by providing ground-truth data on deforestation, land-use dynamics, and signs of vegetation stress, thereby enhancing the accuracy and contextual understanding of remote sensing observations.



Figure 3: Normalized Difference Vegetation Index based on Sentinel 2 data (Sources: Sentinel 2 data: https://dataspace.copernicus.eu/, Belgrade Administrative Boundaries: https://a3.geosrbija.rs/, Software used to process the data: QGIS 3.36.3)

Several initiatives have involved citizens in monitoring vegetation and biodiversity in the Republic of Serbia. One notable example is the Citizen-Enhanced Open Science in Southeastern Europe Higher Education Knowledge Hubs (CeOS_SE) project. This initiative has actively engaged the public, particularly through the observation of the Asian resin bee (*Heriades truncorum*) as part of its citizen science outreach efforts (Citizen-Enhanced Open Science Southeastern Europe. 2022).

In addition to national efforts, citizens from Serbia can participate in several global citizen science platforms that support biodiversity monitoring across urban, rural, and natural environments. iNaturalist is a widely used global initiative offering both a mobile application and a web platform, enabling users to upload photographic observations, contribute species identification data, and interact with a global community of experts and enthusiasts (iNaturalist. 2015). Similarly, the City Nature Challenge is an international bioblitz event aimed at documenting urban biodiversity, encouraging citizens worldwide to observe and record flora and fauna within their cities (City Nature Challenge. 2016).

Currently, there is no comprehensive national project in Serbia that integrates satellite remote sensing with citizen science for monitoring vegetation and biodiversity in urban areas. However, several international initiatives demonstrate the potential of such integrative approaches. For example, Soundscapes to Landscapes (S2L), a NASA-supported project, enlists citizens to deploy portable acoustic recorders to capture bird vocalizations. These data are then combined with satellite imagery to model and map bird species diversity (Earth Data NASA. 2021).

Additionally, the Geo-Wiki platform, developed by the International Institute for Applied Systems Analysis (IIASA), allows volunteers to contribute to environmental monitoring by visually interpreting satellite and aerial imagery. This crowdsourced validation supports global assessments of land cover, vegetation patterns, and land-use change (International Institute for Applied Systems Analysis. 2023).

CONCLUSIONS AND FUTURE WORK

A wide range of satellite data is now available, offering critical insights into the structure and dynamics of urban environments. However, significant challenges remain in extracting high-resolution, site-specific information from these datasets, particularly in heterogeneous urban landscapes. Integrating citizen science with satellite-based remote sensing has emerged as a promising approach to address limitations related to spatial resolution, data precision, and context-specific interpretation.

Several initiatives—such as GLOBE Observer, Geo-Wiki, and Soundscapes to Landscapes (S2L)—demonstrate the value of synergizing satellite observations with ground-level data collected by citizens. These efforts generate rich datasets on variables such as air quality, land cover, and biodiversity, which enhance scientific understanding and support efforts to communicate environmental challenges more effectively. Moreover, such integrated data streams provide valuable tools for policymakers and urban planners, enabling them to design urban spaces that not only align with human needs but also promote and protect urban biodiversity.

Future research should increasingly prioritize the integration of satellite remote sensing with data already generated through citizen science platforms. Developing a unified platform that consolidates these diverse data sources could offer substantial benefits for scientists, decision-makers, and local communities alike. In countries such as the Republic of Serbia, where initiatives combining satellite data and citizen science are currently limited, the development of such projects—guided by best practices from successful global, regional, and local models—could significantly enhance environmental monitoring and urban resilience.

To advance this goal, fostering interdisciplinary collaboration and investing in public engagement and digital infrastructure will be essential steps. Building capacity in both scientific institutions and civil society can ensure that citizen-generated data contributes meaningfully to sustainable urban development.

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