Mapping urban green spaces using an analysis of vegetation indices

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Abstract

The research focuses on the use of advanced remote sensing techniques to combat the effects of climate change in urban areas, with particular reference to heat islands. The proposed methodology, applied to the metropolitan city of Naples, is based on the analysis of very high-resolution satellite images from the WorldView-3 constellation, combining panchromatic and multispectral data through pan-sharpening to obtain detailed maps of urban vegetation, including smaller green spaces such as flower beds, tree-lined avenues, private gardens, green roofs, which are often overlooked because they are difficult to map in a sustainable and widespread manner. Through the calculation of spectral indices (NDVI, MSAVI2, GNDVI, NDRE), the study has enabled not only the precise geolocation of photosynthetically active areas, but also the monitoring of their health status by comparing satellite datasets acquired in June and September 2023. The results highlight marked water stress during the summer period, manifested by a reduction in the average values of the indices. These results constitute a valuable decision-making tool for resilient urban planning and the implementation of Nature-based Solutions, and demonstrate the sustainability and replicability of the methodology in other territorial contexts.

1. Climate change and Green Urban Infrastructure

Urban green areas have a profound impact on the overall ecological balance of cities and on the physical and psychological well-being of the communities that live there. In particular, green infrastructure (GI) plays a strategic role in environmental protection by promoting CO_2 absorption, reducing noise pollution, improving the urban microclimate, and, above all, mitigating the impacts of increasingly frequent and intense heat waves.

In 2023, the Intergovernmental Panel on Climate Change (IPCC, 2023) report stated that the critical threshold of +1.5°C due to ongoing global warming could be exceeded within the next decade, with effects that will be amplified in urban areas. In cities, high rates of urbanisation and intense human activity are already causing a gradual increase in global temperatures, altering the local energy balance and generating the so-called "urban heat island" effect. The consequences of these phenomena include both the deterioration of the health of communities (heatstroke, heat stress, aggravation of respiratory diseases) and vegetation (water stress and loss of biodiversity), as well as an increase in energy consumption for cooling, which causes further greenhouse gas emissions. This leads to further deterioration in air quality with increases in ozone and smog concentrations, triggering a vicious circle that promotes a further increase in temperature (Wan et al., 2025; Zhong et al., 2024).

Combating the heat island phenomenon is therefore one of the most urgent environmental challenges facing contemporary cities as they adapt to climate change. In this scenario, Nature-based Solutions (NbS) represent a winning strategy for achieving carbon neutrality, improving biodiversity, and increasing social well-being (Liu et al., 2024; Tomasso et al., 2025; Zhang et al., 2024). Over the last ten years, there has been exponential growth in scientific research on the centrality of urban green areas as a win-win solution in the field of climate-adaptive design, supporting sustainable urban planning policies to achieve greater ecological and social resilience in cities (Srivastava et al., 2024). These measures involve modifying the reflective and absorbent properties of impervious soil surfaces, increasing ventilation within urban canyons (Abdollahzadeh & Biloria, 2021), replacing traditional cladding and roofing with vertical greening (Dardir & Berardi, 2021; Wang et al., 2022), and green roofs (Tang et al., 2025). Green infrastructure (Benedict and McMahon, 2012) contributes significantly to regulating the urban microclimate through natural mechanisms such as evapotranspiration, canopy shading, and increased surface albedo (Kabisch et al., 2016; Farrugia et al., 2013), offering natural cooling benefits. Numerous international experimental studies show that adequate urban greenery and its distribution can significantly lower local temperatures, by up to 3°C in the most impervious areas (Bowler et al., 2010; Zupancic et al., 2015), while improving the environmental quality and the life quality of communities. In addition to the direct benefit of thermoregulation, urban vegetation provides important socio-environmental co-benefits, including reduced air pollution, regulation of the hydrological cycle, support for biodiversity, and strengthening of social and natural capital in cities (M.E.A., 2005; TEEB, 2010). In this sense, green infrastructure is not only seen as a means of lowering local temperatures but as a multidimensional solution that integrates ecological regulation, social equity, and smart management, while promoting carbon reduction, improving health benefits, and supporting resilient governance.

The real contribution of urban green spaces in mitigating the heat island effect depends not only on their presence but also on other factors that determine their effectiveness, such as their size, spatial configuration, climatic and seasonal factors, the type of ground cover, and the surrounding urban morphology. Large green areas produce extensive and lasting cooling effects, although some studies have shown that, beyond a certain threshold, an increase in green space does not lead to a proportional increase in thermal benefits. Conversely, continuous ecological corridors and irregular but widespread spatial configurations such as flower beds, private gardens, bushes, and tree-lined avenues tend to improve cooling efficiency by expanding the ecological interface with the surrounding environment (Lan et al., 2025). On the other hand, soil sealing associated with urbanisation and infrastructure expansion is a widespread problem as it reduces the percentage of permeable surfaces, increases local temperatures, hinders water absorption, and alters the carbon nutrient cycle, amplifying the effects of extreme weather events.

Therefore, green infrastructure and nature-based solutions (NBS) are recognised as key tools in climate change adaptation policies. This broad recognition has been formalised through international policy instruments, such as the European Strategy for Adaptation to Climate Change, the Nature Restoration Law, and the IPCC recommendations on Nature-Based Solutions (IPCC, 2023). Each of these documents emphasises the importance of adopting a systemic and integrated approach, underpinned by the need to accelerate the implementation of adaptation measures and facilitate access to viable solutions. This process requires a thorough understanding of ecosystem processes to identify priority areas for action, where the climate performance of green spaces can generate maximum benefits in terms of adaptation and mitigation.

Therefore, simulating the effects of heat waves on urban centres using algorithms and predictive models is essential for defining and quantifying specific adaptation and mitigation measures based on green infrastructure, defined by the European Commission as 'strategically planned networks of natural and semi-natural areas with other environmental features, designed and managed to provide a wide range of ecosystem services' (EC, Directorate-General for Environment). To simulate the impact of heat waves, the main indicator used is the mean radiant temperature (MRT), an integrated indicator useful for assessing the effect of heat on the human body and outdoor comfort based on an analysis of urban morphology and vegetation characteristics (Lindberg et al., 2025). Precisely because vegetation significantly influences T_{mrt}, it is essential to identify a capable methodology, first of all, of accurately locating all green areas within the urban core and, subsequently, of monitoring their health status. The results of these in-depth analyses can be incorporated into predictive models to formulate more informed hypotheses about the potential development of green infrastructure, providing an evidence-based decision-support tool that is highly indicative for resilient urban planning.

In this regard, numerous international studies on the subject highlight how attention to green areas often focuses almost exclusively on large vegetated areas, such as parks, urban forests, or public gardens, neglecting smaller, more widespread areas such as flower beds, bushes, tree-lined avenues, and private gardens. From an operational point of view, not including these smaller areas in the green space quantities calculated by algorithms that simulate average urban radiant temperatures means not considering their contribution to improving the local microclimate, resulting in unrealistic predictive models and the risk of developing ineffective planning and design solutions. The precise location and monitoring of these micro-green areas are a complex technical challenge, mainly due to their small size and spatial fragmentation, which makes them difficult to detect and classify with traditional mapping tools. Thanks to the combination of high-resolution satellite imagery, multispectral analysis, and GIS tools, modern ultra-high-resolution remote sensing techniques provide advanced tools to overcome this methodological gap, managing to geolocate even the smallest green spaces and recognising their ecological and social importance.

This paper presents the application to the metropolitan city of Naples of a methodology based on the analysis of very high-resolution panchromatic and multispectral satellite images from the WorldView3 constellation, developed to identify all areas with photosynthetic activity within the urbanised context and to study the actual health of urban greenery by comparing two different time frames (June '23 and September '23) to understand its physiological evolution in relation to climatic variations.

2. Geographical framework of the case study

Established as a Metropolitan City by Law No. 56 of 2014, Naples is one of the most complex territorial realities in southern Italy. With an area of approximately 1,171 km² and a population of over 3 million inhabitants, it is a highly urbanised metropolitan area, characterised by an extraordinary population density (2,600 inhabitants per km² on average) and a complex intertwining of economic, social, and cultural functions. Its territorial configuration is the result of a long process of urbanisation that exploded after the Second World War, leading to the formation of a continuous conurbation that extends well beyond the administrative boundaries of the capital. This phenomenon has generated serious structural problems, profoundly affecting the quality of urban space, infrastructure, the presence of green areas, and levels of liveability.

From an environmental point of view, the area is characterised by high natural vulnerability: the presence of Vesuvius, an active volcano located in the centre of a densely populated area, represents a major geological risk, and the Campi Flegrei area, also of volcanic origin, constitutes a significant risk, aggravated by heavy construction pressure and limited availability of free space for possible evacuations or safety measures.

High demographic pressure has a direct impact on land use, demand for services, and environmental sustainability, exacerbating urban congestion, air pollution, and land consumption, as well as reducing the number of green areas of adequate quality and size to combat climate change and the increasing formation of urban heat islands. Environmental issues are also intertwined with historically poor management of water resources, the sewerage system, and the waste cycle, issues that have fuelled emergencies of national importance over time. In addition, the metropolitan area is also exposed to atmospheric and hydrological pollution resulting from high traffic concentrations, a lack of green areas, and soil contamination in some abandoned or unreclaimed industrial areas.

In summary, therefore, the metropolitan city of Naples is a highly complex area, in which elements of extraordinary historical, landscape, and cultural value coexist alongside profound structural problems that affect its balanced development, including, of primary importance, the issue of urban greenery. Specifically, precisely locating all urban green areas and recognising their state of health is one of the fundamental objectives for understanding the effective contribution that these areas can make to mitigating the urban heat island effect, with a view to sustainable planning that is resilient to the effects of climate change.

The geolocation of areas characterised by photosynthetic activity through the analysis of satellite images from the Worldview3 constellation covered the entire metropolitan city, while the study of the actual health of the green areas was conducted in detail in the eastern part of Naples, with particular attention to the San Giovanni a Teduccio district. This area, historically characterised by manufacturing and industrial activities (textile, metalworking, and food sectors), has undergone a process of deindustrialisation since the 1970s, leaving behind a legacy of abandoned warehouses, contaminated soil, and large urban voids. The percentage of impermeable soil exceeds 70%, while the amount of public green space is well below the city average (approximately 4 m²/inhabitant). This condition results in a marked urban heat island effect, with average radiant temperatures (T_{mrt}) 3-4 °C higher than in greener urban areas, and poor rainwater drainage capacity, causing frequent flooding.

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3. Methodology and data processing

The integration of high spatial and temporal resolution satellite imagery, accurate radiometric indices, and advanced analysis platforms has radically transformed the study of urban greenery, enabling the monitoring of even small, fragmented green areas scattered throughout the built environment, which are difficult to detect using traditional methods.

The use of satellite platforms and unmanned aerial vehicles equipped with the latest-generation sensors (multi- and hyperspectral cameras, LIDAR technology) allows for the continuous analysis of different spectral signatures, recognising different types of land cover and creating detailed maps of vegetation cover and its health conditions. In recent years, advances in satellite imaging technology have significantly improved the accuracy and reliability of these vegetation maps, thanks in part to the integration of machine learning algorithms capable of processing large volumes of multi-source data to distinguish vegetation types, assess their vigour, and monitor changes over time, to better define their actual contribution to adaptive planning in relation to climate change. Thanks to the different temporal resolutions of the various satellite constellations, it is possible to acquire multiple time series of panchromatic and multispectral datasets and monitor green growth trends.

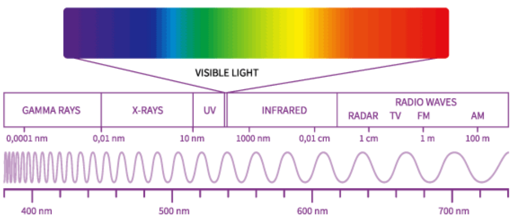


Fig. 1 – Electromagnetic spectrum

From an operational point of view, by analysing the percentage quantities of radiation reflected by leaves in different bands of the electromagnetic spectrum (Fig. 1), it is possible to calculate vegetation indices, i.e., mathematical indicators calculated from the different reflectance values measured by optical sensors at specific wavelengths. These indicators, also known as spectral indices, synthesise multispectral information into a single parameter that quantifies chlorophyll and biomass content, mitigating the disturbing effects produced by radiometric variations, shadows, and the geometry of the vegetation itself (Aldrighettoni et al., 2025; D'Urso et al., 2024).

Although this approach belongs to Precision Farming, developed to improve agricultural productivity and quality standards by reducing processing times, resource use, and environmental damage (Sishodia et al., 2020), the methodological tools employed are well-suited to being applied in the study of large-scale green areas in urban contexts.

In the case study on the metropolitan city of Naples, two satellite images from the Worldview-3 constellation referring to two different time frames (June '23 and September '23) were used as the starting dataset, each consisting of a set of 18 panchromatic images with a spatial resolution of 30 cm and 18 multispectral images with 8 bands and a spatial resolution of 1.24 m.

Since multispectral satellite images have higher spectral resolution than their panchromatic counterparts, but lower spatial resolution (higher ground pixel dimensions), the approach taken was to use pan-sharpening techniques to obtain multispectral colour images with the same pixel dimensions (30 cm) as the panchromatic image. Pan-sharpening is a radiometric transformation that uses a high-resolution panchromatic image to merge with a lower-resolution multiband raster dataset. This produces a multiband raster dataset with the same resolution as the panchromatic raster. This preliminary processing of Worldview3 images, conducted in QuantumGIS, was essential for obtaining a multispectral input dataset with the highest spatial resolution available, from which to set the calculation of the various spectral indices. The choice of resolution of the starting datasets determines the resolution of the expected results: for the identification of smaller green areas such as flower beds, bushes, and tree-lined avenues, a spatial resolution of 30 cm is certainly more effective than a pixel size of 1.24 m. By way of example, Fig. 2 shows the results of this processing: it is possible to appreciate the different pixel size, which defines better sharpness of the edges of buildings and trees, while preserving multiband information.

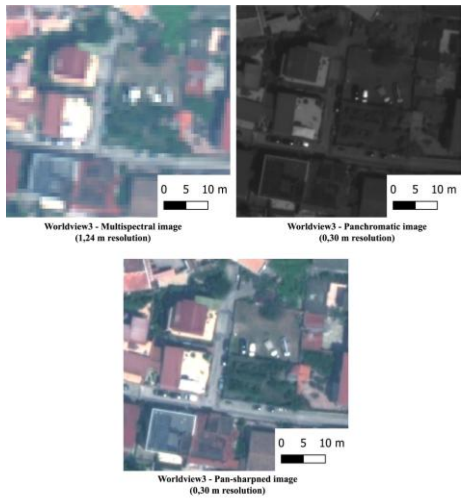


Fig. 2 - Pan-sharpening process

The vegetation indices calculated in this first phase were used exclusively as markers of photosynthetic activity, i.e., as reliable and accurate indicators of the presence, within the various urban areas, of all vegetated spaces, even those of small/medium size (minimum 30 cm).

With this objective in mind, pansharpened images of the city of Naples were processed to calculate, as a priority, the Normalised Difference Vegetation Index (NDVI), which is the most widely used vegetation index for identifying greenery, expressed as:

$$NDVI = \frac{(\rho_{NIR} - \rho_{RED})}{(\rho_{NIR} + \rho_{RED})} \quad (1)$$

where ρ_NIR is the reflectance in the near-infrared band and ρ_RED is the reflectance in the red band. Being a normalised index, the NDVI ranges between -1 and 1, but negative values correspond to areas with non-vegetative cover (water or urbanised areas). Conversely, high values of the index indicate a better state of vigour: the photosynthetically active leaf region absorbs most of the red light in the electromagnetic spectrum and reflects the near-infrared band, while, on the contrary, vegetation under water stress reflects much more red light, absorbing that of the near-infrared.

Fig. 3C shows the global mapping of the NDVI (values >0.3) with a false colour visualisation in shades of green, which, superimposed on the original orthophoto, has made it possible to precisely geolocate urban green areas and quantify their extent.

Subsequently, to study the health status of the identified green areas, other spectral indices were calculated, which, by also using different spectral bands, minimise interference from various external factors (general brightness, canopy shade, and soil reflectance) and highlight specific aspects of the physiological behaviour of the leaf compartments.

The Modified Soil Adjusted Vegetation Index 2 (MSAVI2), for example, which is also calculated using the near-infrared red band, balances and minimises the interference caused by environmental factors such as general brightness, canopy shade and ground brightness, to which the NDVI is highly sensitive. The Green Normalised Difference Vegetation Index (GNDVI) is based on the same algebraic formula as the NDVI but replaces the red band with the green band, thus enabling the determination of water and nitrogen uptake in the canopy and achieving a higher saturation point (it can be used in the presence of dense vegetation or at a more advanced stage of development, unlike the NDVI, which, on the other hand, has a lower saturation point and is therefore more suitable for estimating crop vigour in the early stages of growth/maturation). The Normalised Difference Red Edge (NDRE), on the other hand, proved particularly sensitive to chlorophyll concentration at the leaf level throughout all growth stages, thus enabling the identification of different stages of vegetation development and maturation, as well as the presence of any diseases or infestations (NDVI tends to saturate rapidly in the presence of high biomass content typical of advanced growth stages).

These different indicators, calculated for the entire metropolitan area of Naples using the time series for June 2023 and September 2023, made it possible to quantify the health of the vegetation by comparing the maximum, minimum, and average values of the calculated spectral indices.

$$MSAVI2 = 0.5 * \left[(2\,\rho_{NIR} + 1) - \sqrt{(2\,\rho_{NIR} + 1)^2 - 8\,(\rho_{NIR} - \rho_{RED})}\right] \quad (2)$$

$$GNDVI = \frac{(\rho_{NIR} - \rho_{GREEN})}{(\rho_{NIR} + \rho_{GREEN})} \quad (3)$$

$$NDRE = \frac{(\rho_{NIR} - \rho_{REDEdge})}{(\rho_{NIR} + \rho_{REDEdge})} \quad (4)$$

4. Results and discussion

As a first result, the operations described above made it possible to obtain a precise survey of the areas characterised by photosynthetic activity within the urban core of Naples, thanks to the mapping of the spatial distribution of the values of the various spectral indices calculated. Fig. 3 shows some examples of the results obtained, highlighting the innovative contribution provided by the WorldView-3 images subjected to pansharpening. Thanks to a ground resolution of 30 cm, comparable to that typically achieved by drone surveys, the proposed method has led to the effective identification of all those widespread, fragmented, and often overlooked green areas by lower-resolution satellite products, improving the representation of the urban vegetation network without the need for long and costly acquisition campaigns. The use of these satellite data has therefore ensured systematic and accurate coverage of the entire metropolitan area of Naples with a more favourable cost-time profile than that obtained with UAV platforms. By associating the presence of greenery with the recognition of photosynthetic activity, i.e., positive spectral index values, the classification of vegetated areas was performed by setting a threshold for the NDVI index to minimise the overestimation of photosynthetic activity. Given the complexity and surface heterogeneity of the context, only pixels with NDVI values above the conservative threshold of 0.3 were considered “green” to reduce confusion caused by bare soil, shaded surfaces, and artificial materials.

The high resolution of the results obtained has made it possible to create an updated and accurate map of all the green areas in the city of Naples, as can be seen in views C and D of Fig. 3, which show some detailed focus points, at different scales of representation, of part of the eastern area of Naples (San Giovanni a Teduccio district).

To better highlight the fundamental contribution provided by Worldview3 images, image E shows the clear improvement obtained by applying the proposed methodology compared to the less accurate green space mapping previously available (owned by the municipality), shown in yellow in the figure, dating back to 2019 and created with semi-manual classification of Pleiades images with a spatial resolution of 3 metres.

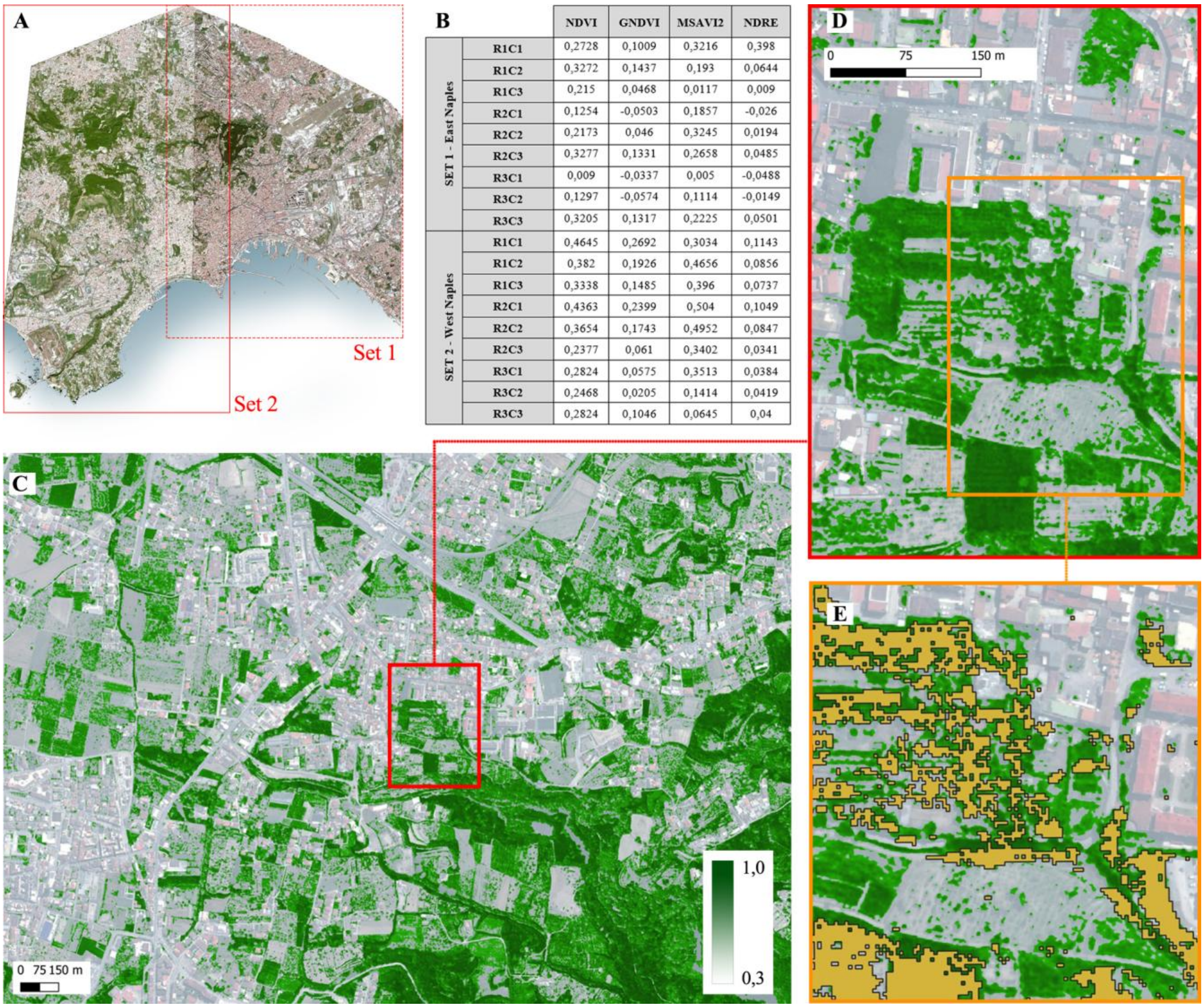
This improvement is crucial since the precise location of all urban green areas is one of the essential input data for the various algebraic models and calculation algorithms that simulate the average radiant temperature and radiation flows in complex urban environments to quantify the contribution of urban greenery to mitigating the heat island phenomenon.

To assess the actual spatial accuracy of the results obtained, a test area (the San Giovanni a Teduccio district) was selected, against which the location of green areas – determined by calculating the NDVI based on WV3 imagery – was compared with a validated real-world dataset provided by an update to the land-use map for that specific area, carried out by the Municipality of Naples in spring 2023 (spatial resolution 1 m). Treating this update as the real-world dataset and the green values derived from NDVI as the predicted values to be validated, the confusion matrix was calculated; this initially yielded an accuracy metric of 0.7066, with a Kappa coefficient of 0.41. The accuracy values thus observed proved to be somewhat inaccurate, consistent with the fact that the compared datasets had different spatial resolutions: the confusion matrix performs a pixel-by-pixel comparison between observed and predicted labels; therefore, resolution discrepancies or imperfect spatial alignment can introduce systematic errors due to mixed pixels and grid misalignment.

To standardise the evaluation, the rasters were resampled to a common resolution using majority resampling, and the accuracy indices were recalculated; following this harmonisation, the overall accuracy derived from the confusion matrix rose to 85%, and the Kappa coefficient stood at 0.68.

This validation confirmed the effectiveness of the proposed methodology, bearing in mind also that the resolution of WV3 images allows for even better spatial resolutions than those considered in the validation phase.

Applying this analytical approach to all spectral indices (MSAVI2, GNDVI, NDRE), it was possible to accurately validate the geolocation of areas with photosynthetic activity. From a quantitative point of view, the averages of the indices, calculated for each image and summarised in Fig. 3B (reference period June 2023), made it possible to immediately identify the areas with the highest concentration of impervious surfaces (low values) compared to those with the highest density of greenery.



		NDVI	GNDVI	MSAVI2	NDRE
SET 1 - East Naples	R1C1	0,2728	0,1009	0,3216	0,398
	R1C2	0,3272	0,1437	0,193	0,0644
	R1C3	0,215	0,0468	0,0117	0,009
	R2C1	0,1254	-0,0503	0,1857	-0,026
	R2C2	0,2173	0,046	0,3245	0,0194
	R2C3	0,3277	0,1331	0,2658	0,0485
	R3C1	0,009	-0,0337	0,005	-0,0488
	R3C2	0,1297	-0,0574	0,1114	-0,0149
	R3C3	0,3205	0,1317	0,2225	0,0501
SET 2 - West Naples	R1C1	0,4645	0,2692	0,3034	0,1143
	R1C2	0,382	0,1926	0,4656	0,0856
	R1C3	0,3338	0,1485	0,396	0,0737
	R2C1	0,4363	0,2399	0,504	0,1049
	R2C2	0,3654	0,1743	0,4952	0,0847
	R2C3	0,2377	0,061	0,3402	0,0341
	R3C1	0,2824	0,0575	0,3513	0,0384
	R3C2	0,2468	0,0205	0,1414	0,0419
	R3C3	0,2824	0,1046	0,0645	0,04

Fig. 3 – A. Satellite coverage of the metropolitan area of Naples divided into two sets, each consisting of nine panchromatic and multispectral images, relating to June 2023; B. Average vegetation index values NDVI, GNDVI, MSAVI2, NDRE, calculated in QuantumGis; C. Example of the precise location of green areas identified by calculating vegetation indices, displaying only values > 0.3 on a green scale, superimposed on the original pansharpened image; D. Detailed focus on the identification of smaller green areas such as flower beds, tree-lined avenues and private gardens; E. Comparison of the quantities of green areas identified using NDVI with the latest available mapping (municipal property), carried out in 2019 in a semi-manual manner using images from the Pleiades constellation (spatial resolution 3m

In Set 1, for example, images R2C1, R3C2 and, in particular, R3C1 have average NDVI and MSAVI2 values that are significantly lower than the others: men $NDVI_{R2C1}$=0.125; mean $NDVI_{R3C1}$=0.009; mean $NDVI_{R3C2}$=0.1297; mean $MSAVI2_{R2C1}$=0.186; mean $MSAVI2_{R2C1}$=0.005; mean $MSAVI2_{R3C2}$=0.111. This is due to the fact that in these areas the percentage of green space is very low, not only because of the significant presence of impermeable surfaces, but also because these areas include part of the sea (which explains the negative values of GNDVI and NDRE).

Another clear consideration concerns the different concentration of green areas between the eastern (Set 1) (Fig.5) and western (Set 2) (Fig.4) parts of Naples. Calculating the arithmetic mean of the average values of the different images in the two sets under analysis, all vegetation indices have higher values in the western part (mean $NDVI_{SET1}$=0.216 - mean $NDVI_{SET2}$=0.337; mean $GNDVI_{SET1}$=0.051 - mean $GNDVI_{SET2}$=0.141; mean $MSAVI2_{SET1}$=0.182 - mean $MSAVI2_{SET2}$=0.340; mean $NDRE_{SET1}$=0.056 - mean $NDRE_{SET2}$=0.069).

An analysis of the morphological conformation of the city shows that this difference is entirely correct, given that the western part of Naples is home to the largest green areas, such as the Camaldoli Urban Park, the Villa Comunale, the Capodimonte Forest, the Virgiliano Park, and the Astroni Nature Reserve. However, despite the presence of these extensive green lungs, it is significant to note that the average spectral values do not exceed 0.5, confirming that impermeable surfaces also have a significant impact in this part of the city.

Furthermore, at a general level, it should be noted that the GNDVI and NDRE indices, linked to the degree of water and nitrogen absorption and chlorophyll concentration, always have lower average values than those of NDVI and MSAVI2, thus highlighting the suboptimal health of the surveyed green areas.

Secondly, a comparative analysis of the vegetation indices calculated in June and September 2023 has highlighted certain variations and issues regarding the health of the vegetation before and after the summer period, although it should be noted that, as only two specific time frames were analysed, the

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spectral indices may also be partially influenced by local external factors, such as temporary weather conditions, lighting and soil moisture.

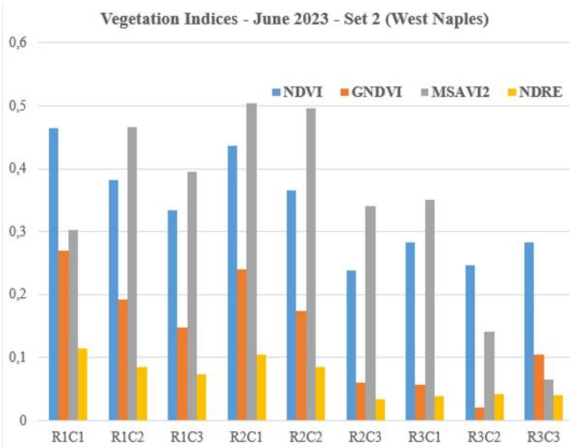

Fig. 4 – Histogram of average index values – June 2023 – Set 2

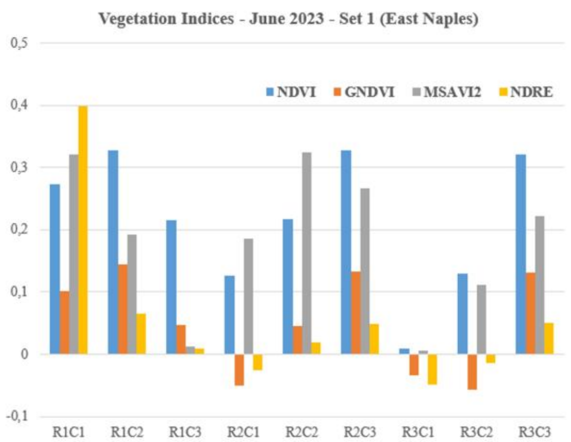

Fig. 5 – Histogram of average index values – June 2023 – Set 1

Fig. 7 shows the graphical and quantitative comparison of the NDVI and MSAVI2 indices calculated in a sample area in eastern Naples (Set 1). In these calculations, to facilitate the comparison of both the different vegetation indices and the values of the same index but referring to the two time frames considered, a false colour output display scale was set, from orange (low values = poor vigour, poor health) to green (very good vigour, healthy vegetation), setting the same intervals for all the indices calculated.

Fig. 6, on the other hand, shows the average values of the spectral indices referring to the two time sets calculated on the sample area of San Giovanni a Teduccio. A comparison of the trends in spectral indices between June and September 2023 immediately reveals a clear reduction in average values, indicating a deterioration in the overall health of the vegetation.

The health of the vegetation in September 2023 appears to be in a poorer state: the calculated indices indicate a sharp reduction in photosynthetic activity (-20% to -30% compared to the values calculated in June 2023) and, consequently, in chlorophyll content and water content at the leaf level, leading to a general increase in water stress.

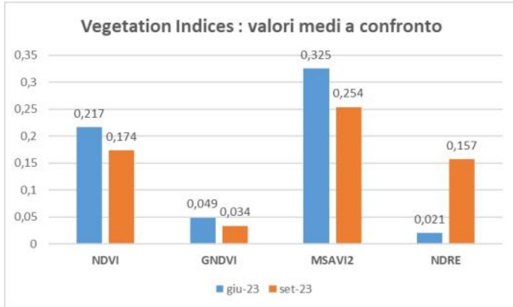

Fig. 6 – Vegetation indices: June-September 2023 comparison

This is significant for understanding how vegetation behaves in response to the difficult climatic conditions of the summer months, during which high temperatures and low rainfall caused considerable stress to the vegetation. This is confirmed by a comparison of the average NDVI and NDRE values (Fig.8, below), which, at first glance, show an anomalous trend. Compared to a ΔNDVI September-June = 0.043, in fact, the NDRE index shows an increase of 7%, going from NDRE June = 0.021 to NDRE September = 0.157: what at first glance might seem to be a trend opposite to that found by the other vegetation indices calculated, in reality fully confirms the increase in water stress of the vegetation downstream of the summer months. When a plant is under stress due to lack of water or nutrients, the NDVI tends to decrease because the vegetation no longer reflects the same amount of NIR light, while the NDRE, on the contrary, may increase due to greater reflection in the red-edge band, which is more sensitive to changes related to photosynthesis in the absence of water and to changes in cell structure (as the vegetation tries to adapt to the new conditions).

5. Conclusions

The methodology proposed and applied to the metropolitan context of Naples provides a significant scientific contribution to the definition of strategies for the planning and sustainable management of urban green spaces, capable of supporting policies aimed at making the city more resilient, inclusive, and attentive to quality of life. These strategies are particularly relevant in responding to the challenges of climate change, population growth, and the transition towards greater ecological sustainability.

The conducted analysis demonstrated that advanced remote sensing techniques, based on panchromatic and multispectral images from the WorldView-3 constellation, represent an effective and sustainable solution for identifying urban greenery. This approach has expanded the ability to detect specific and widespread vegetation elements — flower beds, tree-lined avenues, green roofs, and private gardens — often overlooked by traditional databases due to excessive time and cost to detect them. As a result, it has been possible to geolocate and update the mapping of urban greenery in Naples, generating fundamental input for models and algorithms that simulate average radiant temperature and radiation flows in complex urban environments, which are based on meteorological data, greenery distribution, and building geometry.

Furthermore, the comparative analysis of the different spectral indices made it possible to assess the health of the vegetation surveyed, going beyond its mere spatial presence and providing elements to understand whether green spaces actively and efficiently perform their function of mitigating the urban heat island effect.

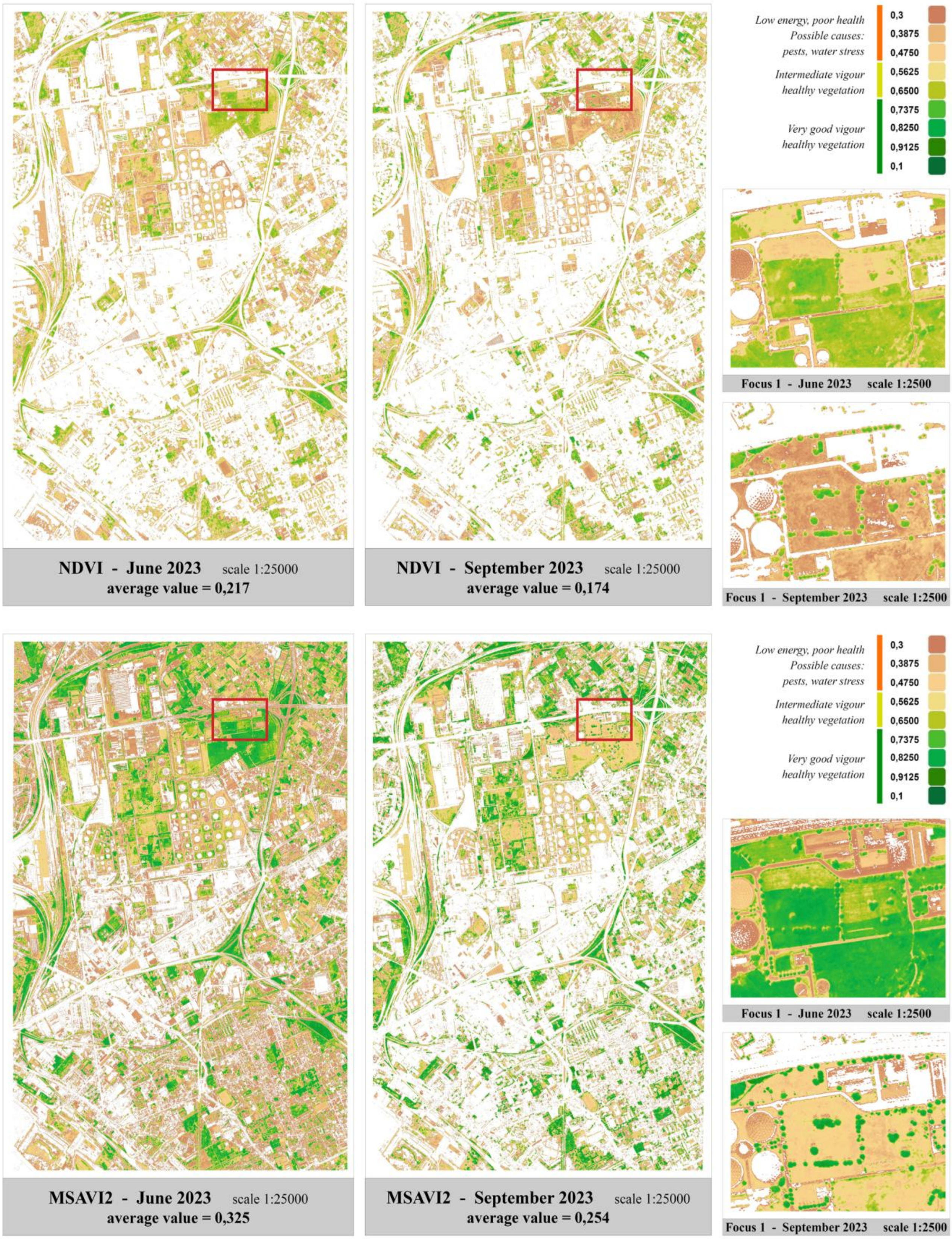

Fig. 7 - Comparison between vegetation indices calculated in June 2023 and September 2023 in the area of San Giovanni a Teduccio, east of Naples. NDVI index (top) and MSAVI2 index (bottom) displayed on a scale of 1:25.000 with a colour scale ranging from red (minimum value 0.3 = poor health) to green (maximum value 1 = excellent vigour). In addition to the average values reported for each index, on the right-hand side, there are two detailed focus areas on a scale of 1:2.500 for both spectral indices, to better understand the differences and the very high spatial resolution achieved through these calculations

https://doi.org/10.5194/isprs-archives-XLIX-B3-2026-871-2026

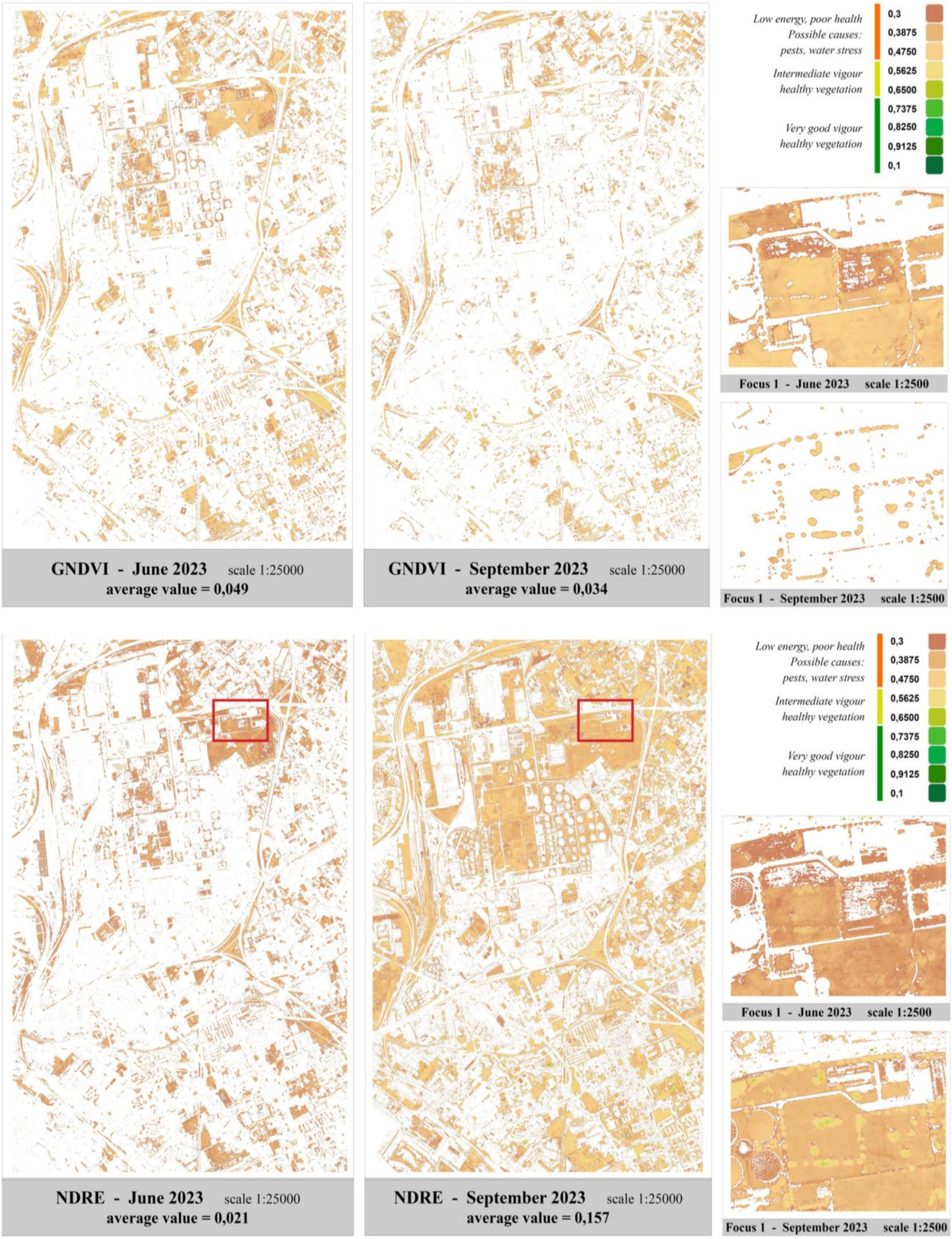

Fig. 8 - Comparison of vegetation indices calculated in June 2023 and September 2023 in the San Giovanni a Teduccio area, east of Naples. GNDVI index (top) and NDRE index (bottom) displayed at a scale of 1:25,000 with a colour scale ranging from red (minimum value 0.3 = poor health) to green (maximum value of 1 = excellent vigour). In addition to the average values shown for each index, on the right-hand side there are two detailed sections at a scale of 1:2,500 for both spectral indices, to better understand the differences and the very high spatial resolution achieved through these analyses

https://doi.org/10.5194/isprs-archives-XLIX-B3-2026-871-2026

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